POSITIVE MOOD AND COGNITION: THE MODERATING ROLE OF APPETITIVE MOTIVATION, NEURAL AND PHYSIOLOGICAL CORRELATES

JESSICA TETCHNER

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DECLARATION

I certify that the work contained in this thesis, or any part of it, has not been accepted in substance for any previous degree awarded to me, and is not concurrently being submitted for any degree other than that of Doctor of Philosophy being studied at the University of Greenwich.

I also declare that this work is the result of my own investigations, except where otherwise identified by references and that the contents are not the outcome of any form of research misconduct

Student: …….

Date: …….

Supervisor: …….

Date: …….

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ABSTRACT

Previous research has found that positive mood results in broader and more flexible cognition, including in relation to control of more complex cognitive processes (e.g., divergent thinking in creativity), as well as those that may be described as being more basic and fundamental (e.g., promoting flexibility over stability in attentional switching). The *neuropsychological theory of positive affect* suggests these effects may be mediated by an increase in dopamine activity. However, the *motivational intensity model* suggests that the effect of positive mood on cognition depends on appetitive motivation, such that only positive mood low in appetitive motivation results in broader/more flexible cognition, whilst narrower/more stable cognition occurs as a result of positive mood that is high in appetitive motivation.

Six studies were conducted to examine the differential influence of positive mood that was high and low in appetitive motivation on cognition, as well as to explore the possible underlying neural and physiological mechanisms, using electroencephalogram (EEG) and spontaneous eye blink rate (EBR) – an indirect measure of dopamine activity. Therefore, Studies 1 and 2 examined the effects of positive mood that were high and low in appetitive motivation on creativity, as well as the effect of these on EBR, and the relationships between EBR and creativity. Studies 3, 4, and 5 also explored these effects/relationships, but in relation to the balance between flexibility and stability in cognitive control. Finally, Study 6 used EEG to examine the effect of these mood inductions on left frontal asymmetry in alpha power, assessed using EEG, and the relationship between this and EBR.

Appetitive motivation was found to moderate the influence of positive mood on divergent thinking in creativity, in line with the directional predictions of the motivational intensity model (i.e., performance was enhanced for the low appetitive induction, but attenuated for the high appetitive induction). There was also some evidence that the low appetitive induction resulted in greater flexibility and reduced stability in cognitive control. However, complementary results (i.e., reduced stability and greater flexibility) were not found for the high appetitive induction. Only the high appetitive induction was found to increase EBR, as well as left frontal asymmetry, suggesting this may be associated with increased dopamine activity in the left prefrontal cortex. In addition, there was also some evidence of a negative relationship between EBR and divergent thinking, as well as a positive relationship with left frontal asymmetry.

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1. Introduction

1.1. Background

Moods and emotions are experienced frequently throughout everyday life, and are suggested to guide our thoughts and behaviour. For example, positive mood has been demonstrated to influence critical thinking, specifically in terms of broadening attention to facilitate alternative, conceptual, and integrative learning (Clore & Palmer, 2009; Nadler, Rabi, & Minda, 2010), as well as facilitating creativity and problem-solving (Politis & Houtz, 2015), and impacting upon decision-making (Duque, Turla, & Evangelista, 2013). Furthermore, positive mood has also been found to influence behaviour. For example, this has been demonstrated to increase prosocial or "helpful" behaviour, such as electing to assist co-workers, contributing to charity, and donating blood (Isen, 1999). Positive mood has also been found to increase variety-seeking behaviour, such as trying new food (Kahn & Isen, 1993), as well as the likelihood of engaging in risky behaviours, such as speeding when driving (M. Chan & Singhal, 2013). Therefore, the study of positive mood is important for understanding how this may influence our thoughts and behaviours in everyday life.

1.1.1. Positive Mood

Affect can be defined as the subjective "feeling" component of mood and emotions (Russell & Feldman Barrett, 2009). Whilst these consist of similar processes (e.g., affect, cognitive appraisals, and action readiness), moods can be distinguished from emotions, as these states are often described as being less intense, of a longer duration, and less strongly related to eliciting objects and events (Ekman, 1992; Frijda, 1993). The study of positive affect is also an important area of research, as it is relevant to affective disorders, such as anxiety and depression, which are associated with a decrease in the experience of positive affect (Nelis, Holmes, & Raes, 2015). However, the experience of positive affect has also been suggested to have important implications for favourable life outcomes in healthy populations, such as physical and mental health (Lyubomirsky, Tkach, & Dimatteo, 2006), performance at work (Wright & Cropanzano, 2000) and the development of social relationships (Lucas, Clark, Georgellis, & Diener, 2004).

The “broaden-and-build theory” (Fredrickson, 1998) suggests that the experience of positive affect may be linked to more favourable life outcomes because this enables an individual to build upon their personal resources that promote survival. For example, engaging in physical exercise, maintaining friendships, expanding intellectual skills, and developing psychological resources (e.g., resilience and optimism). Specifically, positive affect is proposed to signal a safe environment, resulting in broader and more flexible cognition, which facilitates the engagement in novel and exploratory behaviour. This suggestion is supported by findings that positive mood results in a broader attentional scope (Gasper & Clore, 2002), more unusual semantic associations (Isen, Johnson, Mertz, & Robinson, 1985) and categorisations (Isen & Daubman, 1984), flexible reasoning and problem-solving (Isen, Daubman, & Nowicki, 1987), and enhanced creativity on tasks requiring divergent thinking (i.e., producing as many possible answers for a problem as possible) (R. S. Friedman, Förster, & Denzler, 2007).

The neuropsychological theory of positive affect (Ashby, Isen, & Turken, 1999) suggests that positive mood results in broader and more flexible cognition due to an increase in dopamine activity in two areas of the brain – the basal ganglia and the prefrontal cortex. This has been supported by findings that genetic differences relating to dopamine activity may predict performance on tasks that require broad and flexible cognition, such as creativity tasks assessing divergent thinking (Reuter, Roth, Holve, & Hennig, 2006). Support has also come from behavioural studies that have examined spontaneous eye blink rate (EBR), which is suggested to reflect dopamine activity in the basal ganglia (Jongkees & Colzato, 2016). These studies demonstrate that cognitive flexibility (e.g., creativity) is optimal at a medium EBR (Chermahini & Hommel, 2010), and that the effect of positive mood on creativity depends on baseline differences in EBR (Chermahini & Hommel, 2012).

1.1.2. Cognitive Control

Positive affect has also been found to influence more basic and fundamental cognitive processes (cf., complex cognitive processes, such as creativity). Goal-directed behaviour is proposed to require an antagonistic balance between flexible and stable modes of cognitive control, which may provide complimentary context-dependent costs and benefits for behaviour (Goschke & Bolte, 2014). Specifically, flexibility is argued to be beneficial when switching to new goals, but costly in terms of increasing distractibility. In contrast, stability is argued to be beneficial for shielding active goals from distraction, but may be costly in terms of increasing perseverative behaviour (inappropriate persistence of a thought or action). Using paradigms

designed to assess these specific processes, positive affect has been found to result in greater flexibility (but increased distractibility) (Dreisbach & Goschke, 2004), and to reduce stability (but increase perseveration) (Dreisbach, 2006).

Neurobiological models of cognitive control suggest that greater stability in cognitive control may reflect increased dopamine activity in the prefrontal cortex, particularly in relation to a specific sub-type of receptor neurons, referred to as D1 receptors (Durstewitz & Seamans, 2008). Flexibility is suggested to reflect greater dopamine activity in the basal ganglia, particularly in relation to D2 sub-type receptor neurons (Frank & O'Reilly, 2006). Therefore, positive affect has been suggested to result in an increase in this latter activity, facilitating greater flexibility in cognitive control (Goschke & Bolte, 2014). EBR is proposed to reflect this D2 activity in the basal ganglia (especially when assessed at baseline) (Jongkees & Colzato, 2016), and individual differences have been found to result in similar findings to positive affect, such that greater flexibility in cognitive control has been observed for those with a greater EBR (Dreisbach et al., 2005).

1.1.3. Appetitive Motivation

Studies described up until this point have demonstrated that positive affect results in broader and more flexible cognition. However, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the impact of positive affect depends on motivational intensity. Positive affect can be described as being high or low in appetitive motivation, which refers to the drive that an individual experiences in response to appetitive or rewarding stimuli (Depue & Collins, 1999). Positive affect low in appetitive motivation (i.e., feelings experienced "post-goal" that are associated with "consummation" or "liking") is suggested to result in broader and more flexible cognition, facilitating exploratory behaviour to discover new goals and opportunities (Carver, 2003). However, positive affect high in appetitive motivation (i.e., feelings experienced "pre-goal" that are associated with "anticipation" or "wanting") is suggested to result in narrower and more stable cognition, facilitating focus on the pursuit of rewards or appetitive goals (Gable & Harmon-Jones, 2010).

The motivational intensity model (Gable & Harmon-Jones, 2010) has been supported by studies demonstrating differential effects for positive mood that is high and low in appetitive motivation on attentional scope. Specifically, whilst positive affect low in appetitive motivation results in a broader attentional scope, positive affect high in appetitive motivation has been found to result in a narrower attentional scope (Gable & Harmon-Jones, 2008b).

Positive affect low in appetitive motivation has also been found to result in greater flexibility in cognitive control (at the cost of increased distractibility), whilst positive affect high in appetitive motivation has been found to result in attenuated flexibility (decreased distractibility) (Liu & Wang, 2014). The differential effect of positive mood states varying in motivational intensity in relation to performance on paradigms designed to assess stability in cognitive control has been examined in one study (Wacker, 2017). However, the mood induction was not found to effectively induce positive states that were high and low in appetitive motivation, and no effects were observed.

Alternatively, the reward-as-motivation hypothesis (Goschke & Bolte, 2014) proposes that appetitive stimuli or rewards result in greater stability in cognitive control because these increase motivation to engage in effortful control (Aston-Jones & Cohen, 2005). This hypothesis is supported by findings that offering performance-based reward incentives results in attenuated flexibility (Muller, Dreisbach, Goschke, et al., 2007), and greater stability in cognitive control (Frober & Dreisbach, 2014). Unlike the motivational intensity model (Gable & Harmon-Jones, 2010), this hypothesis argues that appetitive stimuli must be related to performance to result in greater stability. However, it is assumed that positive affect that is unrelated to task performance (i.e., not associated with pursuit of a reward/appetitive goal) results in greater flexibility. Therefore, Liu and Wang's (2014) findings (i.e., two states of positive affect unrelated to task performance had differential effects on cognitive control based on motivational intensity) are not consistent with this hypothesis.

In relation to the neurobiological basis of appetitive motivation, positive affect high in appetitive motivation is suggested to be associated with an increase in dopamine activity in the nucleus accumbens and the prefrontal cortex, whilst positive affect low in appetitive motivation is associated with other neural substrates (Depue & Collins, 1999). This is supported by animal studies (Berridge, 2009), as well as and human studies demonstrating that “wanting” responses (Leyton et al., 2002), desire (Volkow et al., 2002), excitement, and euphoria (Drevets et al., 2001) are associated with dopamine activity, whilst “liking” (Chelnokova et al., 2014) and pleasantness (Eikemo et al., 2016) are predominantly associated with opioid activity. Interestingly, positive affect that is high in appetitive motivation has also been associated with an increase in activity specifically in the left frontal areas (Gable & Harmon-Jones, 2008a). This has led to the suggestion that an increase in dopamine activity associated with appetitive motivation may be lateralised to the left hemisphere of the brain (Tomer et al., 2014).

Based on this literature, it may be suggested that positive affect high in appetitive motivation results in narrower and more stable cognition due to an increase in dopamine in the (left) prefrontal cortex, specifically resulting in greater D1 activity. However, positive affect that is low in appetitive motivation may be suggested to result in broader and more flexible cognition due to an increase in dopamine in the basal ganglia, specifically resulting in greater D2 activity. Therefore, the current research will investigate how positive affect influences cognitive control, in relation to both complex and more basic/fundamental processes, whilst taking into account motivational intensity. (i.e., examining possible differences in the effects of positive affect that is high and low in appetitive motivation). It will also (indirectly) explore differences in the neural activity that may occur as a result of these types of positive affect (i.e., dopamine activity in the basal ganglia vs. prefrontal cortex), and whether this activity underlies the influence of positive affect on cognition.

Statement of Problem

Positive mood has consistently been found to result in enhanced performance on creativity tasks that assess divergent thinking (Davis, 2009). However, the differential influence of positive mood states that are high and low in appetitive motivation has not been examined in relation to creativity. Based on the motivational intensity model (Gable & Harmon-Jones, 2010), it may be expected that these positive mood states, varying in level of appetitive motivation, could differentially influence divergent thinking, as this requires broad and flexible thinking. More specifically, whilst positive affect low in appetitive motivation may be beneficial for this process, positive affect high in appetitive motivation may be detrimental. Furthermore, an increase in dopamine activity in the basal ganglia (i.e., increased EBR) has been demonstrated to be a possible mechanism underling the effect of positive mood on divergent thinking (Chermahini & Hommel, 2012). However, this has not yet been explored in relation to positive mood states that vary in motivational intensity.

Positive affect has also been found to influence cognitive processes that may be more fundamental and basic, such as the balance between flexibility and stability in cognitive control. Specifically, positive affect has been found to result in greater flexibility (Dreisbach & Goschke, 2004) and reduced stability in cognitive control (Dreisbach, 2006). However, reward incentives have been found to have the opposite effect, resulting in greater stability (Frober & Dreisbach, 2014) and reduced flexibility (Muller, Dreisbach, Goschke, et al., 2007). Only one study to date has effectively demonstrated that these differential effects also occur for positive affect that is high compared to low in appetitive motivation (Liu & Wang, 2014).

This supports the motivational intensity model (Gable & Harmon-Jones, 2010) and is inconsistent with the alternative reward-as-motivation hypothesis (Goschke & Bolte, 2014). However, this study (and others in this area) have used briefly presented images to induce positive affect, eliciting only transient emotional responses (e.g., Dreisbach & Goschke, 2004; Frober & Dreisbach, 2014; Liu & Wang, 2014). Therefore, it is currently unclear whether these effects can be extended to more enduring positive mood states.

Flexibility in cognitive control is suggested to be related to an increase in D2 activity in the basal ganglia (Frank & O'Reilly, 2006), whilst stability in cognitive control is related to an increase in D1 activity in the prefrontal cortex (Durstewitz & Seamans, 2008). This is supported by findings that flexibility is greater for those with a higher EBR at rest (i.e., greater levels of dopamine in the basal ganglia) (Dreisbach et al., 2005). However, it is unclear whether this activity underlies the influence of positive affect on cognitive control processes. Positive affect high in appetitive motivation has been demonstrated to be related to greater activity in left frontal areas (Gable & Harmon-Jones, 2008a), but this has not been demonstrated in comparison to positive affect that is low in appetitive motivation. Furthermore, greater left activity at rest has been linked to individual differences in prefrontal dopamine activity (Tomer et al., 2014). However, dopamine activity has not yet been demonstrated to be involved in the influence of positive mood on greater left frontal activity.

It is currently unclear whether appetitive motivation moderates the influence of positive mood on cognition, in relation to both more complex cognitive processes (e.g., creativity), and more fundamental processes (e.g., the balance between flexibility and stability in cognitive control). This has important implications for developing understanding of affective disorders, such as depression, as this is not only associated with the reduced experience of positive affect, but also cognitive impairments, such as deficits in problem-solving, planning, decision-making, memory, and concentration (Hammar & Ardal, 2009). These impairments have been suggested to have a negative impact on the everyday life of patients, resulting in problems at work, and with family and social relationships (Lam, Kennedy, McIntyre, & Khullar, 2014). Therefore, further research examining the influence of positive mood on cognition may help to elucidate understanding of these deficits in patients with affective disorders, such as depression, and contribute to the development of effective interventions (McIntyre, 2016).

The experience of positive affect has also been associated with more favourable life outcomes in healthy populations. This includes a more successful career at work (Wright & Cropanzano, 2000), as well as developing more social relationships (G. R. Lee & Ishii-Kuntz, 1987).

Positive affect has also been found to be related to better physical health (Lyubomirsky et al., 2006), better mental health (Koivumaa-Honkanen et al., 2001), and an older age of death (H. S. Friedman et al., 1993). These more favourable life outcomes have been proposed to be related to the influence that positive affect has on cognition (i.e., broader/more flexible), such that this promotes exploratory behaviour, which allows personal resources, that are beneficial to survival, to be developed (Fredrickson, 1998). Therefore, understanding how specific types of positive mood may influence cognition may help to further explain the relationship between positive affect and these more favourable life outcomes.

The neurobiological mechanisms underlying the differential effect of positive mood states that are high and low in appetitive motivation on cognitive processes are also unclear at present. However, understanding of these mechanisms is important for the effective treatment of affective disorders, such as depression. For example, treatment of depression currently favours the administration of drugs that target neural substrates outside of the dopamine system, such as serotonin activity (Cowen & Browning, 2015). However, these drugs are not always observed to reduce symptoms of depression, which is suggested to be due to the involvement of other neural systems in this disorder, such as dopamine activity (Blier & El Mansari, 2013). This has led to the suggestion that treatment options should include drugs that target dopamine activity to effectively reduce symptoms of depression (Hori & Kunugi, 2012). Therefore, further research to understand the role of dopamine in positive mood and the effect of this on cognition may have important implications for future treatment options for affective disorders, such as depression.

1.2. Purpose of Research

The current research aims to investigate how positive affect influences cognition, in relation to more complex cognitive processes (i.e., divergent thinking in creativity), as well as in relation to more basic and fundamental processes (i.e., the balance between flexibility and stability in cognitive control). It extends previous research to examine these aims specifically in relation to more enduring mood states (c.f., transient emotional responses) that are high and low in appetitive motivation. The neural activity (i.e., dopamine activity in the basal ganglia and prefrontal cortex) that may underlie these effects will also be explored, using indirect physiological measures indicative of this activity (i.e., EBR and EEG). This extends previous research by examining differences in activity for positive mood states that are high and low in appetitive motivation, and allows for a more in-depth analysis of the relationship between this

activity and cognition. This may have far reaching implications for the treatment of cognitive impairments in affective disorders, as well as for promoting more favourable life outcomes in healthy populations.

To achieve this, the first part of the thesis will examine the influence of positive mood states that are high and low in appetitive motivation on the more complex cognitive processes involved in creativity. The influence of these mood states on EBR will also be examined, as well as how EBR may be related to creativity, and whether individual differences in EBR moderate the effects of positive mood on these processes. The second part of the thesis will examine the influence of positive mood states that are high and low in appetitive motivation on more basic and fundamental cognitive processes. Specifically, this will involve examining the influence of these positive mood states on the balance between flexibility and stability in cognitive control. Again, the effect of positive mood states that are high and low in appetitive motivation will be examined in relation to EBR. The relationships between EBR and these processes, and whether this moderates the effect of positive mood on the balance between flexibility and stability in cognitive control, will also be examined. In the last part of the thesis, the effect of positive mood states on activity specifically in the left frontal areas of the cortex will be examined using EEG, as well as the relationship of this activity to EBR.

2. Literature Review

This chapter provides a review of the background literature that is relevant to the current research, and this is presented in four sections. Section 2.1 covers the definition, structure, importance, and function of positive mood, as well as the influence of this on complex cognitive processes (e.g., creativity), and the possible neurobiological mechanisms that may underlie these effects. Section 2.2 outlines literature relating to more basic and fundamental cognitive processes (e.g., balance between flexibility and stability in cognitive control), describing these in relation to goal-directed behaviour, which is followed by literature examining the influence of positive affect on these processes, and the possible underlying neurobiological mechanisms. Section 2.3 introduces appetitive motivation, and covers literature relating to the influence of positive mood states that vary in motivational intensity on cognitive processes. Again, possible neurobiological mechanisms relating to these effects are discussed. Finally, the chapter ends with a summary of the literature and then provides the aims of the current research (Section 2.4).

2.1. Positive Mood

This section defines key terms that are often used interchangeably in the literature, which is followed by a description of the structure of affect. The importance of studying positive affect will then be outlined, in relation to affective disorders and advantageous life outcomes in healthy populations. Theoretical work proposing that positive affect may function to promote broader and more flexible cognition will then be described, and empirical work will be reviewed in support of this theory. This will include research that has examined the influence of positive mood on processes relating to attention, cognition, and creativity. This will be followed by a description of the "neuropsychological theory of positive affect" (Ashby et al., 1999), which suggests that an increase in dopamine levels may underlie these effects (i.e., the suggestion that positive mood results in broader and more flexible cognition). Finally, empirical evidence for this theory will be reviewed, which includes genetic studies and studies examining EBR (proposed to be a marker of dopamine activity).

2.1.1. Definition, Structure, and Function

2.1.1.1. Affect, Mood, and Emotion

After almost a century of debate surrounding the conceptual nature of emotion, there is still controversy as to how this construct should be defined (Scherer, 2009). However, there is general agreement that emotions can be considered to be a complex set of multiple interrelated processes, occurring due to specific antecedent objects or events (Frijda & Scherer, 2009; Russell & Feldman Barrett, 1999). One of these processes can be referred to as core affect, which is defined as the "neurophysiological state consciously accessible as a simple primitive non-reflective feeling" (Russell & Feldman Barrett, 2009, p. 104). It refers to an individual's awareness of the feelings in relation to their own current state, and cannot be reduced any further as a psychological component (Russell, 2003). Other distinct processes include cognitive appraisal (i.e., in relation to meaning and relevance), and the preparation of action readiness (Frijda & Scherer, 2009; Russell & Feldman Barrett, 1999).

Although "mood" and "emotion" are often used interchangeably in the literature, moods are more diffuse and global than emotions (i.e., having only vague or temporally remote causes), such as being tense about one's future (Frijda, 1993; Morris, 1989). Mood is suggested to consist of the same multiple components as emotions, including core affect. However, these are typically less intense and are not tied to specific objects or events (Ekman, 1992; Frijda, 1993). Furthermore, whilst emotions typically last for seconds or minutes, moods can last for hours, days, or even weeks in the case of affective disorders, such as depression (Ekman, 1992; Russell, 2003). Therefore, despite involving similar processes, particularly in terms of core affect, there is a conceptual distinction between moods and emotions (i.e., moods have more temporally remote causes, are less intense, and typically longer in duration).

2.1.1.2. Dimensions of Affect

Early work describing the structure of core affect proposed categorisation of discrete states reflecting a set of basic affect types, such as anger, disgust, fear, joy, sadness, and surprise (Ekman, Friesen, & Ellsworth, 1982). This approach was supported by factor analyses demonstrating that discrete categories of affect consistently emerged across studies of momentary reported affect (McNair, Lorr, & Droppleman, 1971; Zuckerman & Lubin, 1985). However, strong interrelations between different categories led to the development of

dimensional models, in which the structure of affect was composed of a number of smaller dimensions (Diener, Smith, & Fujita, 1995; Watson & Clark, 1997). For example, Thayer (1989) suggested that the primary dimension of affect was activation – the energy, tension, or behavioural readiness in affect, whilst Watson and Tellegen (1985) emphasised valence – the degree to which affect is positive or negative.

Based on theoretical conceptualisations (Reisenzein, 1994), work eventually converged on two separate and equal dimensions of valence and activation in affect. It was suggested that the valence and activation structure of affect could best be presented in the form of a circumplex model (Russell, 1980), with a vertical axis representing the valence dimension and a horizontal axis representing the activation dimension. This creates four segments, in which distinct affective categories can be then be grouped, such that interrelations are reflected by the proximity of categories along the circle's circumference. More recent work has expanded this circumplex model to add additional points based on valence and activation. Initially providing eight segments for affective categories (Larsen & Diener, 1992), and then twelve (Yik, Russell, & Steiger, 2011) – displayed in Figure 2.1

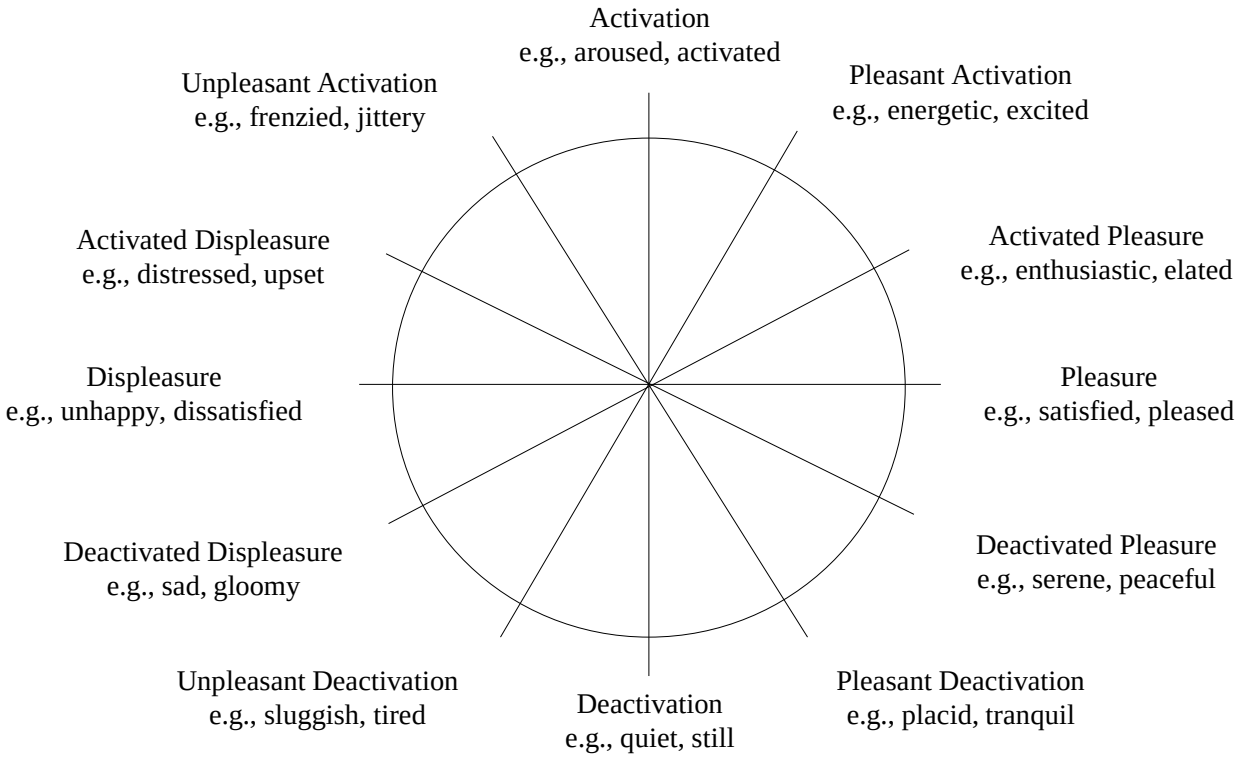


Figure 2.1. *Schematic diagram of the locations of the twelve segments of core affect with primary axis representing activation and valence dimensions that are incorporated in the 12-Point Affect Circumplex, adapted from Yik et al. (2011).*

2.1.1.3. Importance of Positive Affect

The study of affect has traditionally been dominated by research primarily relating to negative affect, possibly due to the importance of this in affective disorders, such as anxiety and depression (Fredrickson & Branigan, 2001). However, symptoms of depression and anxiety do not only include an increase in negative affect, but also a decrease in the experience of positive affect and a loss of interest in daily activities (Nelis et al., 2015). Other affective disorders are also primarily associated with the abnormal experience of positive affect. For example, during manic phases of bipolar disorder (Gruber, 2011), and aberrant pleasure-seeking as part of addiction (Saah, 2005). Therefore, one reason why the study of positive affect is important is for elucidating understanding of these disorders and developing effective treatments for these. However, the study of positive affect is also relevant at a wider level for society, as the experience of this is associated with important outcomes in healthy populations (Lyubomirsky, King, & Diener, 2005).

For example, cross-sectional studies have found that positive affect is positively correlated with overall physical and mental health in the general population, as well as negatively correlated with visits to the hospital and doctor's surgery, medications that are used, and absences from work (Gil et al., 2004; Lyubomirsky et al., 2006). There have also been positive correlations demonstrated between positive affect and sleep quality/quantity, amount of exercise, use of functional coping strategies, as well as negative correlations with alcohol intake and cigarette use (Bardwell, Berry, Ancoli-Israel, & Dimsdale, 1999; C. C. Chen et al., 1996; Lox, Burn, Treasure, & Wasley, 1999; Pettit, Kline, Gencoz, Gencoz, & Joiner, 2001). Furthermore, longitudinal studies have demonstrated that the experience of less positive affect predicts suicide, depression, heart disease, stroke, whilst greater positive affect predicts an older age for death (H. S. Friedman et al., 1993; Koivumaa-Honkanen et al., 2001; Kubzansky & Kawachi, 2000; Ostir, Markides, Peek, & Goodwin, 2001).

Positive affect has also been associated with favourable outcomes, outside of those more direct measures of physical and mental health, which are described above. For example, cross-sectional studies have also found positive correlations between positive affect and job performance, whilst longitudinal studies have demonstrated positive correlations between positive affect and supervisory evaluations at five years, offers for second interviews at three months, and income at nineteen years (Burger & Caldwell, 2000; Diener & Biswas-Diener, 2002; Wright & Cropanzano, 1998, 2000). In addition, positive affect has also been found to

be important for developing social relationships, with cross-sectional findings demonstrating positive correlations for the number of close friends an individual has and social participation (G. R. Lee & Ishii-Kuntz, 1987; D. L. Phillips, 1967), and longitudinal findings demonstrate a positive correlation for marital status at four years (Lucas et al., 2004).

2.1.1.4. The Broaden-and-Build Theory

The "broaden-and-build theory" (Fredrickson, 1998) explains the relationship between positive affect and favourable life outcomes, by suggesting that positive affect functions to allow personal resources to be built. These resources are suggested to include health benefits (i.e., engaging in physical exercise), creating and maintaining friendships and support networks, developing intellectual skills and knowledge, as well as psychological resources (i.e., resilience and optimism). To build these resources, it is argued that positive affect broadens the repertoire of available perceptions, thoughts, and actions that are accessible to an individual. Therefore, broader and more flexible response tendencies are available, allowing the individual to engage in novel thoughts, activities, and relationships. Thus, positive affect is proposed to serve an adaptive function, as resources are assumed to be durable and stored in reserve for use at a later date, promoting an individual's chance of survival.

2.1.2. Influence on Cognition

2.1.2.1. Attentional Scope

Attentional scope refers to the amount of information that is currently selected as relevant to behaviour (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006). This is suggested to vary in size, such that a broader attentional scope results in a greater amount of information being processed, whilst a lesser amount of information is processed as a result of a narrower attentional scope. This has been described as analogous to a spotlight beam, such that information in the beam is processed at the expense of information at other locations (Posner & Peterson, 1990). However, elsewhere attentional scope has been argued to be more analogous to the zoom lens of a camera (Eriksen & St James, 1986). This is based on the proposition that there is a trade-off between size and processing efficiency (i.e., a broader attentional scope results in more information being processed with a coarse resolution, whilst a narrower attentional scope results in less information being processes, but with a finer resolution).

Navon (1977) describes a broader attentional scope as promoting a global processing bias – attention is drawn to the abstract features of the whole stimulus, whilst a narrower attentional scope promotes a bias towards local processing – attention is drawn to the specific details of a stimulus. To demonstrate this effect, Navon (1977) designed a paradigm, in which participants were presented with a large letter (i.e., global feature) consisting of smaller letters (i.e., local feature). Response times (RTs) were assessed when participants responded to these, and were found to be faster for local features on congruent trials (i.e., same response is associated with global and local features) compared to incongruent trials. However, congruency was found to have no effect for global targets, suggesting a general bias towards global processing and a broader attentional scope, which has consistently been replicated in other studies (Eriksen & St James, 1986; Kimchi, 1992; Navon, 2003).

A similar paradigm to the Navon (1977) letter task (adapted from Kimchi & Palmer, 1985) requires participants to identify whether a larger shape (e.g., triangle) formed of smaller incongruent shapes (e.g., squares) is most similar to a shape matching the global or local features of the target. In line with previous findings, a global bias on this paradigm has been demonstrated to occur under neutral conditions (Kimchi, 1992). However, Gasper and Clore (2002) found that participants who recalled a 'happy and positive' autobiographical memory subsequently identified more global (i.e., compared to local targets) than those who recalled a neutral memory. The same results were also found in a separate study using this paradigm for participants who watched positive film clips (i.e., evoking amusement and contentment) compared to neutral film clips (Fredrickson & Branigan, 2005). Therefore, these studies suggest that positive mood may result in a more global mode of processing and a broader attentional scope (Eriksen & St James, 1986).

The Eriksen flanker task requires participants to respond to a central target stimulus letter that is flanked by distractor letters, which can be either compatible (i.e., associated with same response as the target) or incompatible. Rowe, Hirsh, and Anderson (2007) manipulated the spacing of the flankers on this task (i.e., to be closer or more distant from the target), providing a measure of attentional scope. Participants engaged in mental imagery and listened to music to induce either a neutral or positive (i.e., "happy") mood before performing the task. For both mood inductions, RTs were found to be slower on incompatible "close" trials, suggesting increased distractor interference. However, slower RTs were found on incompatible "distant" trials, but this was only the case for those in a positive mood. Therefore, this suggests an

increase in the spatial focus of attention, and as such, a broadening of attentional scope as a result of positive mood.

Although these results support the broaden-and-build theory (i.e., positive affect resulted in broader attention) (Fredrickson, 1998), Bruyneel et al. (2013) suggested that other studies using the Eriksen flanker task have produced inconsistent findings. For example, no differences in compatibility effects were found when Martin and Kerns (2011) examined performance on this task following a positive (i.e., amusing film clips) compared to a neutral mood induction. There were also no differences in compatibility effects on this task in a study conducted by Finucane, Whiteman, and Power (2010), which compared the effect of a positive (i.e., images presented prior to each trial) to a neutral induction. Although the study conducted by Rowe et al. (2007) did find that positive mood resulted in greater compatibility effects, the more important finding in this study was that this effect was dependent on the spacing of the flankers (i.e., most pronounced when further from the central target).

Therefore, perhaps these other studies would have found an effect of positive mood if the spacing of flankers was taken into account. However, Bruyneel et al. (2013) conducted two separate experiments, examining the effect of different positive mood inductions (i.e., personally relevant feedback and recall of 'happy' memories whilst listening to music), on the Eriksen flanker task, taking into account the spacing of flankers. Despite this, no differences in compatibility effects were found following positive (i.e., compared to a neutral) mood inductions. Therefore, this suggests that a broadening effect of positive mood on attentional scope may be unreliable, or that this may be dependent on other factors. For example, the duration of the mood inductions used in this study were shorter compared to in Rowe et al.'s (2007) study. Although self-report measures suggested that mood was successfully induced, this may not have carried as effectively over the experimental period.

2.1.2.2. Associations and Categorisation

It has been suggested that "positive affect produces a broad and flexible cognitive organisation and the ability to integrate diverse material" (Isen, 1990, p. 89). For example, Isen et al. (1985) examined the unusualness of word associations provided by participants. Affect was manipulated by presenting participants with either positive (i.e., rated as pleasant) or neutral words, for which they were required to provide the first word that came to mind. The unusualness of associations was assessed based on word-association norms from a large sample of college students using three derivations of unusualness (e.g., given by fewer than 2.5% of

respondents). Participants who had viewed the positive words were found to give more unusual associations on all three measures, compared to those participants who had viewed neutral words. Furthermore, in a second experiment, the authors found that participants provided more unusual associations for neutral (and positive) words following two different positive mood inductions (i.e., watching an amusing film clip or receiving a gift) compared to a neutral induction.

An increase in the likelihood of producing diverse associations as a result of positive affect has also been demonstrated in relation to categorisation tasks. For example, Isen and Daubman (1984) presented participants with a category word (e.g., vehicle), for which they were required to indicate (using a Likert-type scale) how well exemplars fitted within this category. These exemplars varied in the strength of their association with the category word, and were determined to require either strong associations (e.g., truck) or weak associations (e.g., elevator), based on normative data (Rosch, 1975). Following positive mood inductions (i.e., watching amusing film clips or receiving gifts), participants were found to make higher ratings of fit for weak associations, compared to a neutral mood induction. Similar results have also been demonstrated by Isen, Niedenthal, and Cantor (1992) for ratings of fit between categories of social stereotypes (e.g., entertaining people) and exemplars requiring strong (e.g., a clown) and weak (e.g., a college professor) associations.

2.1.2.3. Reasoning and Problem-Solving

The influence of positive affect has also been examined in relation to performance on tasks that require flexible problem solving, such as Duncker's (1945) candle problem. Within this task, participants are presented with a box of tacks, a candle, and a book of matches, and are instructed to attach the candle to the wall so that it will burn without dripping wax on to the floor. The correct solution requires the participant to empty the box of tacks and affix this to the wall to use as a platform for the candle. However, finding this solution requires the participant to consider alternative uses for the box (i.e., as a platform) rather than its dominant use (i.e., as a container). Research has demonstrated that displaying the box and tacks separately or labelling all of the items presented to participants facilitates performance (R. E. Adamson, 1952; Glucksberg & Weisberg, 1966). This, presumably, increases the accessibility of alternate uses of the box, supporting the suggestion that flexible reasoning is required in order to find the correct solution in this task.

Isen et al. (1987) compared performance on Duncker's (1945) candle problem following a neutral mood induction and two positive mood induction conditions (i.e., watching an amusing film or receiving a gift). Performance (assessed as the number of participants able to find the correct solution in a ten-minute period) was found to be enhanced for those who watched the amusing film, compared to a neutral mood induction. However, performance was not found to be significantly different for participants who had received a gift. Examination of self-reported affect completed after the mood inductions demonstrated that this condition did not result in greater positive affect, which is suggested to explain the lack of effect on performance. The authors suggest that this may have been due to a failure to wrap the gift, which could have resulted in a less effective mood induction, compared to other studies in the field that follow a similar procedure.

Carnevale and Isen (1986) examined performance on an integrative bargaining task, which required participants to play the role of buyers and sellers, in order to reach an agreement on the price of household commodities. Those participants who underwent a positive mood induction (viewing amusing cartoon comic strips) prior to the task achieved a higher joint profit compared to those who did not. This was suggested to reflect the fact that positive mood had resulted in more flexible negotiating. In addition, Estrada, Isen, and Young (1997) presented physicians with a hypothetical medical problem, and these participants were asked to think aloud when considering a diagnosis. Transcripts were rated for inflexibility towards new relevant information that was potentially disconfirming in relation to the participant's current hypothesis. Those participants who underwent a positive mood induction (i.e., receiving gifts prior to the task) were rated as displaying less inflexibility (i.e., more flexibility), again suggesting that positive mood enhances flexibility in cognition.

2.1.2.4. Creativity and Divergent Thinking

Creativity can be defined as "a person's capacity to produce new or original ideas, insights, restructuring, interventions, or artistic objects, which are accepted by experts as being of scientific aesthetic, social, or technological value" (Vernon, 1989, p. 94). This definition describes creativity in terms of the production of outcomes that are novel or unique, but that have usefulness or value. Guilford (1967) proposes that two processes contribute to creativity: i) divergent thinking – the process of generating many different and diverse ideas or solutions to a problem, leading to the formation of unexpected connections between these; and ii) convergent thinking – the process of deriving the ultimate solution to a problem from a number

of ideas, requiring logic and evaluation to reach a decision. Therefore, it may be suggested that divergent thinking contributes to creativity by facilitating the production of outcomes that are novel and unique, whilst convergent thinking enables the determination of outcomes that are the most useful or have the most value.

Elaborating on divergent thinking, Guilford (1967) suggested that this process is characterised by: i) fluency – number of ideas; ii) flexibility – variety of ideas; iii) originality – unique ideas; and iv) elaboration – detailed ideas. To assess divergent thinking, Guilford (1967) developed the Alternate Uses Task, which requires participants to provide as many appropriate uses of a household object (e.g. "a cup") as possible. Performance is examined for: i) fluency – the total number of responses; ii) flexibility –the number of responses from different categories of idea (e.g., "to store pens" and "a paperweight" are uses from different categories, whilst "to store pens" and "to store spare change" are uses from the same category); iii) originality – the number of responses that are unusual compared to norms within a sample; and iv) elaboration – the amount of detail provided within each response (e.g., "to store pens" is a less detailed response in comparison to "you can put pens inside a big cup so that these can be easily reached when working at the desk, which means you then you don't need to hunt around for one").

Isen (1990) suggests that positive affect results in a broader/more flexible cognitive organisation, as well as more diverse associations between distant cognitive elements, which may be beneficial for divergent thinking. This may allow a greater number of uses to be produced (i.e., fluency), from a variety of different categories (i.e., flexibility), which increases the likelihood of an unusual idea being produced (i.e., originality). Support comes from experimental studies that examined the effect of positive mood inductions (i.e., recall of "pleasant" autobiographical memories or watching amusing film clips) on the Alternate Uses Task. For example, fluency and flexibility have been found to be increased compared to negative or neutral mood inductions (R. S. Friedman et al., 2007; Tan & Qu, 2014). Furthermore, Vosburg (1998) found that self-reported positive mood (i.e., in the absence of a mood induction) was positively correlated with fluency and flexibility, and that there was a weak (i.e., non-significant) positive correlation with originality.

Positive mood has also been found to influence performance on figural tasks from the Torrance Tests of Creative Thinking (Torrance, 1974), which assesses divergent thinking using non-verbal methods. For example, in one subtest of these scales, participants are presented with a series of shapes (e.g., a circle) and are required to draw as many objects using these shapes as possible. These drawings can then be used to assess the characteristics of divergent thinking

using similar methods to the Alternate Uses Task. Recently, Fernández-Abascal and Díaz (2013) found that, in the absence of a mood induction, self-reported positive mood was positively correlated with performance on this picture completion subtest, and that performance was significantly greater following a positive mood induction (i.e., using amusing film clips) compared to a negative mood induction. However, it should be noted that although the authors state that fluency, flexibility, originality, and elaboration were assessed, results were based on a singular "mean Torrance Tests of Creative Thinking score".

The influence of positive mood on creativity has also been examined using Mednick's (1962) Remote Associates Test. Within this task, participants are presented with three seemingly unrelated words (e.g., "cream", "skate", "water"), and must identify a word that semantically links all three together (e.g., "ice"). Divergent thinking is required to access diverse associations between the three seemingly unrelated words, but it should be noted that (unlike the Alternate Uses Task and the picture completion subtest of the Torrance Test of Creative Thinking), this task also requires a significant component of convergent thinking to derive the correct solution (C. S. Lee, Huggins, & Therriault, 2014). Despite this, Isen et al. (1987) found that following a positive mood induction (i.e., presentation of gifts), the number of correct solutions on this task was greater, compared to a neutral mood induction. These results have been replicated by Estrada, Isen, and Young (1994), using a similar mood induction procedure, and by Rowe et al. (2007), using music and mental imagery to induce a positive mood.

Interestingly, in Rowe et al.'s (2007) study, a positive mood induction was not only found to enhance performance on the Remote Associates Test, but performance on this task was also found to correlate with the degree of broadening in attentional scope as indicated by RT spacing compatibility effects on a flanker task (see Section 2.1.2.1). Further support of a link between the effects of positive mood on attentional scope and divergent thinking comes from a study by R. Friedman, Fishbach, Forster, and Werth (2003), which manipulated attentional scope prior to performance on cognitive tasks in two experiments. Participants completed tasks that required attention to be broadly or narrowly focused (e.g., visual search tasks across broad or narrow areas) and then completed the Alternate Uses Task or were required to provide an unusual exemplar of a category (e.g., birds) in the other. Participants who were primed with a broader attentional focus scored higher on originality in the Alternate Uses Task and produced more unusual exemplars than those primed with a narrower attentional focus.

2.1.3. Neurobiological Mechanisms

2.1.3.1. The Neuropsychological Theory

The range and variety of behavioural evidence suggesting that positive affect results in broader and more flexible cognition has generated work to elucidate the neural mechanisms underlying these effects. The neuropsychological theory of positive affect (Ashby et al., 1999) suggests that these effects may be due to increases in dopamine activity, which is a neurotransmitter. This refers to a chemical released from the synapse of a neuron, which in effect, transmits information to another neuron. There are several distinct dopamine systems in the brain, but the neuropsychological theory draws on two of these specifically: i) the nigrostriatal pathway, which projects from the substantia nigra to the basal ganglia, and is suggested to be involved in mediating motor responses (Groenewegen, 2003); and ii) the mesocorticolimbic pathway, which projects from the ventral tegmental to the frontal and limbic areas, including the prefrontal cortex and nucleus accumbens. This system is suggested to be involved with activity relating to the processing of reward and motivation (Yamaguchi, Wang, Li, Ng, & Morales, 2011).

Within the neuropsychological theory of positive affect (Ashby et al., 1999), it is proposed that moderate levels of dopamine are present under neutral conditions, but that positive affect stimulates increases in the projection of dopamine along both of these pathways. Consequentially, dopamine levels in the prefrontal cortex are increased, which is proposed to facilitate the entry of new information into working memory. This is suggested to enable the selection of the appropriate cognitive set (i.e., activation of mental representations related to a particular concept or task). Simultaneously, an increase in dopamine levels in the basal ganglia is proposed to facilitate a switch in attention from an old to a new cognitive set. Therefore, these increases in dopamine levels are argued to result in positive affect facilitating the activation of non-dominant sets, and the ability to overcome the activation of those sets that are more dominant (i.e., switching away from sets activated frequently to activate those that are less frequently selected), thus enabling broader and more flexible cognition.

Ashby, Valentin, and Turken (2002) suggested how an increase in dopamine levels may mediate the previously observed effect of positive mood on performance in Duncker's (1945) candle task (e.g., Isen et al., 1987). To find the correct solution in this task, the dominant cognitive set (i.e., the box as a container) must be overcome, and the less dominant set (i.e., the box as a platform) must be activated. An increase in mesocorticolimbic and nigrostriatal

dopamine as a result of positive mood may facilitate activation and switching to the less dominant cognitive set. Therefore, this may explain previous findings that positive affect results in more participants being able to find the correct solution on this task (Isen et al., 1987). Furthermore, this mechanism may also account for findings that positive affect facilitates access to more diverse associations (e.g., Isen & Daubman, 1984). For example, in a word association task, if participants are given the word 'pen', dominant sets (i.e., the pen as a writing instrument) may be overcome, allowing the selection of, and switching to, less dominant or less frequently activated cognitive sets (i.e., the pen as an enclosure).

Ashby et al. (2002) also proposed that increases in mesocorticolimbic and nigrostriatal dopamine levels accounts for findings that positive mood results in enhanced creativity on divergent thinking tasks (Isen et al., 1987). For example, in the Remote Associates Test, this mechanism was suggested to facilitate the overcoming of dominant sets associated with each of the three words that were presented to a participant (e.g., club, gown, and mare), allowing the participant to select and shift attention to less dominant sets. This was argued to enable the participants to access distant semantic associations, and activate the correct response linking the words together (e.g., night). Using a computational model, Ashby et al. (2002) simulated performance on Duncker's (1945) candle task, a word association task, and the Remote Associates Test. Higher and lower dopamine levels facilitating the activation of dominant and less dominant cognitive sets were used to represent states of positive and neutral affect respectively. Simulated performance was compared to findings from previously conducted behavioural studies (i.e., Isen et al., 1987, 1985), and the results were found to closely match the findings of these studies.

2.1.3.2. Genetic Studies

Genetic studies have also provided support for some aspects of the neuropsychological theory of positive affect (Ashby et al., 1999). These studies compare performance on divergent thinking tasks, for participants with genetic differences that are related to dopamine activity. For example, Reuter et al. (2006) examined performance on the inventiveness battery of the Berlin Intelligence Structure Test (Jager, Sub, & Beauducel, 1997), which requires participants to produce as many uses for objects as possible, as well as to complete similar tasks to assess creativity across figural, verbal, and numeric domains. The authors examined individual differences in relation to the DRD2 gene, which encodes dopamine receptors predominantly in the basal ganglia, and specifically in relation to the DRD2/ANKK1 Taq Ia polymorphism,

which determines the density of these receptors. It was found that performance was enhanced for A1+ carriers (i.e., lower dopamine receptor density) compared to A1- carriers (i.e., greater dopamine receptor density). Therefore, this supports a link between dopamine activity in the basal ganglia and divergent thinking performance.

Another genetic study examining individual differences in divergent thinking performance and variation in genes relating to dopamine activity was conducted by Mayseless, Uzefovsky, Shalev, Ebstein, and Shamay-Tsoory (2013). This examined the DRD4 gene, which also encodes receptor neurons primarily in the basal ganglia, specifically in relation to a polymorphism resulting from a variable number of tandem repeats located in the region of exon III. Carriers of the 7-repeat allele (i.e., associated with higher levels of dopamine in the basal ganglia) were found to have enhanced performance on the Alternate Uses Task, as well as on the figural tasks from the Torrance Tests of Creative Thinking. Therefore, this provides support for the involvement of nigrostriatal dopamine in divergent thinking task performance. However, Reuter et al.'s (2006) study found that genetic markers indicative of lower dopamine levels resulted in enhanced creativity, which is not in line with the directional predictions of the neuropsychological theory of positive affect (i.e., greater dopamine activity enhances divergent thinking) (Ashby et al., 1999).

One possible explanation as to why findings from genetic studies may not be in line with the specific directional predictions of the neuropsychological theory of positive affect (Ashby et al., 1999) may be that the effects of genes are likely to be dependent on complex interactions. For example, Zabelina, Colzato, Beeman, and Hommel (2016) examined performance on a shortened version of the Torrance Tests of Creative Thinking, in relation to two genes: DAT (associated with dopamine reuptake in the basal ganglia) and the catechol-O-methyltransferase (COMT) (associated with dopamine availability in the prefrontal cortex). Whilst there were no differences in divergent thinking observed for carriers of different alleles relating to these genes when examined independently, multiple interactions between these were found to influence performance. Similar findings have also been observed elsewhere in the literature. For example, (Runco et al., 2011) found divergent thinking task performance was dependent on interactions between several genetic polymorphisms, including those relating to DAT, COMT, and DRD4 genes.

2.1.3.3. EBR

Genetic testing can often be ethically invasive for participants and is expensive for researchers (McPherson, 2006). Therefore, other studies have relied on EBR (i.e., number of eye blinks per minute), which has been used as an indirect physiological measure of dopamine levels in the basal ganglia. This is based on evidence from clinical (and pharmacological/neuroimaging – see Section 2.2.3.4) studies, which have found differences in EBR in samples of patients with disorders that are associated with aberrant dopamine activity, compared to healthy populations. For example, Parkinson's disease is a neurological disorder that is associated with progressive dopamine depletion in the substantia nigra, and thus lower levels of dopamine activity in the basal ganglia (Damier, Hirsh, Agid, & Graybiel, 1999; Jankovic, 2011). Clinical studies have consistently demonstrated that patients with Parkinson's disease have a lower EBR compared to matched controls (Aksoy, Ortak, Kurt, Cevik, & Cevik, 2014; Biousse et al., 2004; Deuschl & Goddemeier, 1998; Fitzpatrick, Hohl, Silburn, O'Gorman, & Broadley, 2012; Karson, LeWitt, Calne, & Wyatt, 1982).

A meta-analysis of studies examining the differences in EBR for patients with Parkinson's disease compared to healthy populations concluded that there was clear evidence of a reduction in EBR for patients when studies were combined (Fitzpatrick et al., 2012). Further support also comes from studies that have demonstrated that EBR is reduced for patients at a later (compared to earlier) stage of the disorder (Agostino et al., 2008), as well as for patients displaying more severe (compared to less severe) symptoms (Karson et al., 1982). In addition, Parkinson's disease is treated through the administration of the metabolic pre-cursor for dopamine, levodopa (L-dopa), which has been demonstrated to result in an increase in EBR for patients taking this medication (compared to those who are not) (Agostino et al., 2008; Bologna, Conte, Suppa, & Berardelli, 2012; Kimber & Thompson, 2000). Therefore, there is consistent evidence that EBR is reduced in patients with Parkinson's disease.

Another disorder associated with aberrant dopamine activity is schizophrenia, which is specifically related to the hyperactivity of receptors in the basal ganglia (Howes, McCutcheon, & Stone, 2015). Studies have consistently demonstrated that patients diagnosed with schizophrenia have an elevated EBR in comparison to matched controls (T. A. Adamson, 1995; E. Y. Chen, Lam, Chen, & Nguyen, 1996a; Helms & Godwin, 1985; Jacobsen et al., 1996; Karson, Freed, Kleinman, Bigelow, & Wyatt, 1981; Mackert, Flechtner, Woyth, & Frick, 1991; Mackert, Woyth, Flechtner, & Volz, 1990; Mackert, Woyth, Flechtner, & Frick, 1988; Stevens,

1978; Swarztrauber & Fujikawa, 1998). Also, cross-sectional studies have demonstrated positive correlations between EBR and schizophrenic symptomology (R. C. Chan & Chen, 2004; E. Y. Chen, Lam, Chen, & Nguyen, 1996b), and a longitudinal study demonstrated an increase in EBR for schizophrenic patients between initial diagnosis and a three-year follow-up point (L. P. Chen et al., 2010). Furthermore, this study also found that increases in EBR over this period predicted an increase in the symptomology at the follow-up point.

Treatment for schizophrenia involves the administration of neuroleptic (i.e., antipsychotic) drugs, such as chlorpromazine and haloperidol, which are dopamine antagonists (Li, Snyder, & Vanover, 2016). Two studies have demonstrated that treatment with chlorpromazine over a number of weeks reduced EBR, and that this reduction was positively correlated with improvement in clinical symptoms (T. A. Adamson, 1995; Mackert et al., 1990). However, another study found that treatment with neuroleptic drugs resulted in a non-significant decrease in EBR (Mackert et al., 1988), although this may have been due to a failure to exclude patients with a history of taking neuroleptic drugs, which was supported by a subsequent study demonstrating that EBR was reduced only for drug naive patients (Mackert et al., 1991). Other studies have also demonstrated that treatment with haloperidol over a number of weeks resulted in a reduced EBR, and that this decrease in EBR was correlated with a reduction in schizophrenic symptomology (Karson et al., 1982).

2.1.3.4. Inverted U-Shaped Relationship

Clinical evidence suggests that EBR reflects nigrostriatal dopamine activity (i.e., dopamine levels in the basal ganglia). Therefore, based on the neuropsychological theory of positive affect (Ashby et al., 1999), it may be expected that EBR would be positively related to divergent thinking performance. However, Chermahini and Hommel (2010) examined the relationship between EBR and performance on the Alternate Uses Task, finding that, rather than a linear association between these variables, EBR was in fact related to divergent thinking in a quadratic inverted U-shape[1]. This suggests that performance was optimal for those with a medium EBR (i.e., a moderate level of dopamine activity in the basal ganglia), whilst those individuals with a higher or lower EBR (i.e., excessive or insufficient levels of dopamine

[1] An inverted U-shape has also been found for relationships between dopamine activity and cognition in domains outside of creativity. For example, attention (Dang, Xiao, Liu, Jiang, & Mao, 2016), inhibition (Colzato, van den Wildenberg, & Hommel, 2007), and working memory (Cools & D'Esposito, 2011).

activity) demonstrated attenuated performance (see Figure 2.2). This may help to explain inconsistent findings for the effect of dopaminergic genes on divergent thinking, as it is unclear where carriers of certain alleles may be situated on this inverted U-shape, which may be dependent on the interaction of genotypes.

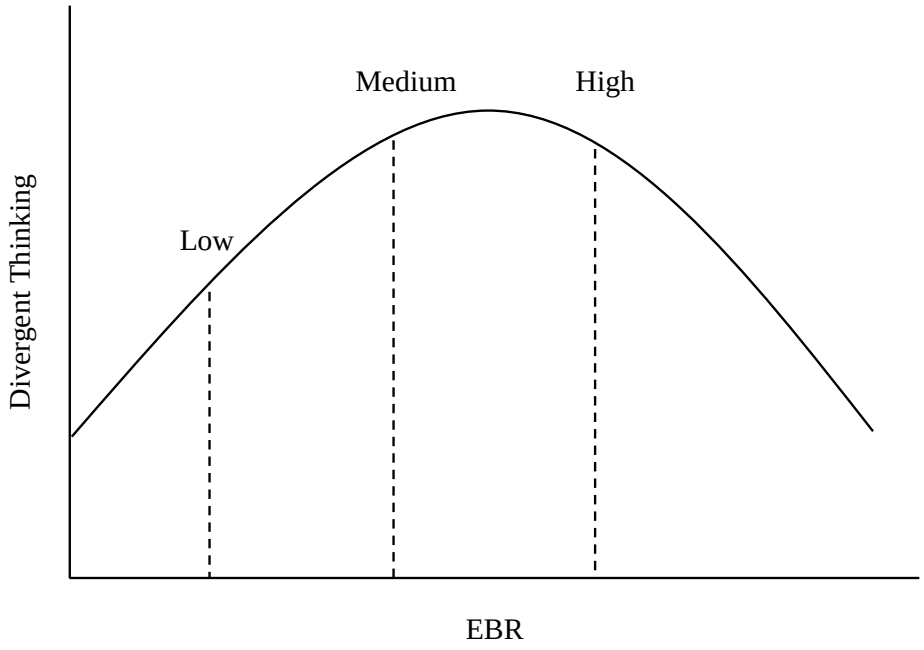


Figure 2.2. *Hypothetical relationship between EBR and divergent thinking task performance, reflecting the moderating role of individual differences in baseline dopamine function, based on Chermahini and Hommel (2010, 2012). Mild increases in dopamine as a result of positive mood is proposed to result in a: large increase in performance for individuals with low baseline levels of dopamine, a small increase in performance for individuals with medium levels of dopamine, and a decrease in performance for individuals with high baseline levels of dopamine.*

Despite this, the Chermahini and Hommel (2010) study (and genetic studies outlined in Section 2.1.3.2) suggests that individual differences in dopamine activity in the basal ganglia are related to divergent thinking. However, these studies do not examine the influence of positive mood on this relationship, which is of central importance to the neuropsychological theory of positive affect (Ashby et al., 1999). To recap, this theory proposes that positive mood results in an increase in nigrostriatal dopamine projection, which facilitates flexibility in cognition (e.g.,

divergent thinking). In fact, only one study to date, conducted by Chermahini and Hommel (2012), has investigated this proposition. This study found that a positive mood induction (i.e., recall of a "happy" autobiographical memory) resulted in enhanced divergent thinking, as well as a significant increase in EBR. Furthermore, increases in positive affect were found to be related to increases in divergent thinking, which was also found to be the case for increases in EBR. However, a negative mood induction had no effect/was unrelated to EBR and divergent thinking performance, suggesting effects were specific only to positive mood.

Chermahini and Hommel (2012) also examined the relationship between EBR and divergent thinking prior to the positive mood induction (e.g., at baseline). A non-linear inverted U-shaped relationship was again observed between performance on this task and baseline EBR. A median split was then performed based on baseline EBR, to produce groups of those with higher vs. lower baseline EBR. Positive affect was found to result in enhanced divergent thinking, but only for those participants with a lower baseline EBR, whilst no difference was found for those with a higher EBR. Therefore, this study provides support for the neuropsychological theory of positive affect (Ashby et al., 1999), as the positive mood induction was found to result in increases in EBR, as well as enhanced divergent thinking, suggesting that an increase in nigrostriatal dopamine activity may underlie these effects. However, these findings also suggest that enhanced divergent thinking due to positive mood may be moderated by individual differences in baseline EBR (i.e., resting level of dopamine activity in the basal ganglia).

2.1.4. Interim Summary

Core affect can be defined as the state experienced by individuals during moods and emotions, which includes properties of activation (i.e., high/low arousal) and valence (i.e., positive/negative). This can be best represented in the form of a circumplex, split into four primary sections based on activation and valence. Further sub-dimensions have been added in recent models, such as the 12-PAC (Yik et al., 2011), which includes twelve sections of affect. Mood and emotions contain the same component processes (including core affect), but can be distinguished as mood states are generally less intense, of a longer duration, and more vaguely related to causal objects and events. Research into positive affect is an important area, as this is relevant for affective disorders, and has been associated with favourable life outcomes in healthy populations. The broaden-and-build theory (Fredrickson, 1998) suggests that positive affect is related to these outcomes as it facilitates the building of durable personal resources,

by facilitating broader and more flexible cognition, allowing individuals to engage in novel and more exploratory behaviour.

The broaden-and-build theory (Fredrickson, 1998) is supported by experimental studies examining the effect of positive mood inductions (generally involving affective film clips, mental imagery, or presenting participants with gifts) on attention and cognition. These studies have found that positive mood facilitates a broadening of attentional scope, in terms of resulting in a more global bias of attention (i.e., attention is drawn to the general features of a stimulus, rather than the more local or specific details) and an increase in the spatial focus of attention. Furthermore, positive mood has also been found to result in access to more diverse or unusual associations and categorisations, more flexible reasoning and problem solving, and enhanced creativity – particularly on tasks requiring divergent thinking (i.e., the process of generating many different and diverse ideas). This has been assessed using the Alternate Uses Task (Guilford, 1967) (e.g., providing as many alternate uses for an object as possible) or the Remote Associates Test (Mednick, 1962) (e.g., finding the semantic link between three seemingly unrelated words).

To explain the neural mechanisms underlying these findings, the neuropsychological theory of positive affect (Ashby et al., 1999) proposes that positive mood increases mesocorticolimbic and nigrostriatal dopamine. This is proposed to facilitate the updating of working memory and the switching of attention towards new cognitive sets, which allows dominant sets to be overcome and less dominant sets to be activated. This has been supported by studies demonstrating that there are individual differences in divergent thinking (e.g., on the Alternate Uses Task), which are dependent on genetic variations that influence dopamine activity in the basal ganglia. However, findings from these genetic studies are not always in line with the directional predictions of the neuropsychological theory of positive affect (Ashby et al., 1999). It is suggested that this may be because the relationship between broader/more flexible cognition and dopamine activity is likely to be dependent on a complex interaction between a number of different genes (including those relating to dopamine activity in the prefrontal cortex), which has been supported by findings from other genetic studies.

Other studies have examined the relationship between EBR and cognition, as this has been found to be reduced in patients with Parkinson's disease, but elevated in patients with schizophrenia, leading to the suggestion that EBR may reflect dopamine activity in the basal ganglia. Chermahini and Hommel (2010) found an inverted U-shaped relationship between EBR and divergent thinking performance, suggesting that medium levels of nigrostriatal

activity may be optimal for broader/more flexible cognition. Furthermore, Chermahini and Hommel (2012) found that a positive mood induction resulted in an increase in EBR, and enhanced divergent thinking, but only for those with a lower EBR at baseline (i.e., prior to the induction). This supports the neuropsychological theory (Ashby et al., 1999), as it suggests that positive mood enhances divergent thinking due to increases in nigrostriatal dopamine. However, it also suggests that performance is optimal at moderate levels of dopamine, and that the effect of positive mood is dependent on baseline levels, which may also contribute to the inconsistent findings observed in genetic studies.

2.2. Cognitive Control

This section outlines the more basic and fundamental cognitive processes that may be influenced by positive affect (c.f., more complex cognition, such as creativity, discussed in the previous chapter). These processes will be defined in relation to the cognitive control of goal directed behaviour (i.e., the balance between the stabilisation and active maintenance of goal-relevant representations in working memory vs. updating and flexible shifting of attentional focus to new goal representations). This is followed by the presentation of empirical work investigating how positive affect may influence these processes using different cognitive control paradigms. Neurobiological models of cognitive control relating to dopamine activity are then described, and empirical evidence supporting these models is presented. Finally, a more in-depth examination of the specific neural activity reflected by EBR will be provided, and this will be discussed in relation to the influence of positive affect on these basic and fundamental cognitive processes.

2.2.1. Goal-Directed Behaviour

2.2.1.1. Cognitive Control Processes

Although cognitive control is a difficult concept to define (Morton, Ezekiel, & Wilk, 2011), this term broadly refers to the adaptive configuration of cognitive processing, which functions to facilitate optimal performance during goal-directed behaviour (E. Miller & Cohen, 2001). Therefore, cognitive control allows information processing and behaviour to vary from moment to moment, depending on the current goals of the individual. Whilst a broad range of processes are involved in cognitive control, factor analyses and structural equation modelling (i.e., using a battery of tasks to assess cognitive control) have suggested the involvement of

three primary processes (Miyake et al., 2000): i) "shifting" – switching attention between cognitive sets; ii) "updating" – monitoring and moderation of working memory contents; and iii) "inhibition" – overriding of pre-potent (habitual) responses and resistance to distractor interference. From these primary processes, it is suggested that more complex cognition occurs, such as planning, reasoning, problem-solving, and creativity (Diamond, 2013).

However, Miyake and Friedman (2012) suggested that, whilst the three primary processes outlined above (i.e., shifting, updating, and inhibition) share common variance, this completely subsumes that inhibition factor. Therefore, this led to the proposition that this common variance may represent the active maintenance of contextual information in working memory, used to bias processing down-stream in cognitive control (Munakata et al., 2011). Here, the term "contextual information" refers to information that is relevant to the interpretation of goals, and mediates an appropriate behavioural response, such as representations of rules that are related to task performance (J. D. Cohen & Servan-Schreiber, 1992). However, unique variance in shifting and updating factors has been suggested to represent partly separable processes, possibly reflecting the ease of transitioning to new representations and the effective gating of information entry (Miyake & Friedman, 2012).

2.2.1.2. Shifting-Shielding Dilemma

Goal-directed behaviour is proposed to place antagonistic demands on these primary processes, specifically in relation to the balance between flexibility and stability that is required in cognitive control (Goschke, 2000). For example, listening to a lecture whilst ignoring background noise requires goal-relevant contextual information to be maintained and shielded from distraction (i.e., stability in cognitive control). However, this may result in difficulties switching to a new relevant goal when required (i.e., increased perseveration), such as if a colleague asked you a question directly. In contrast, switching to a new goal, such as listening and responding to the question asked by a colleague, requires updating working memory representations and shifting attentional focus (i.e., flexibility in cognitive control). However, this may result in greater interference from irrelevant information (i.e., increased distractibility), such that it may become harder to ignore background noise or the noise from the lecture, which has now become irrelevant to the active goal.

Therefore, the balance between flexibility and stability in cognitive control may be suggested to have context-dependent costs and benefits for goal-directed behaviour, which has been referred to as the "shielding-shifting dilemma" (Goschke & Bolte, 2014). This antagonistic

relationship has been supported by studies using cognitive tasks that require participants to categorise a target, presented simultaneously with distractors (e.g., the Flanker task – see Section 2.1.2.1). Faster RTs have been consistently observed on trials following those with incompatible distractors (i.e., associated with a different response to the target) (Egner, 2007), which may result from increased demand for the active maintenance of task-relevant information, due to greater conflict on the previous trial. However, this increase in active maintenance has been found to result in slower RTs when the task requires the participant to switch to a new rule for responding (Meiran, Hsieh, & Dimov, 2010).

2.2.1.3. Proactive and Reactive Control

The "dual-mechanisms of control framework", describes two antagonistic control modes that rely on flexibility and stability in cognitive control, which are referred to as "proactive" and "reactive" control (Braver, 2012). Proactive control refers to the active maintenance of contextual information that its goal relevant, prior to and in the anticipation of interference. Representations are sustained continuously, resulting in new information being less likely to enter working memory, resulting in bottom-up information being less able to capture attention (i.e., stability in cognitive control). However, reactive control refers to the bottom up reactivation of goal relevant information upon interference or due to episodic demands. Goal relevant information is not being continuously maintained, and as such, new information is able to enter working memory more easily, resulting in bottom-up information being more able to capture attention (i.e., flexibility in cognitive control).

2.2.2. Influence of Positive Affect

2.2.2.1. Flexibility

To examine the effect of positive affect on flexibility in cognitive control, studies have often used set-shifting paradigms. These require an individual to complete a cognitive task that requires switching between rules relating to different task-sets (i.e., the particular parameters that allow task-specific processes to be performed), such as switching between responding to digit or letter stimuli. This includes processes relating to perceptual encoding, attention orienting, memory retrieval, response selection, and response execution (Logan & Gordon, 2001). Switching between task-sets results in "switch costs" (i.e., increased RTs and error rates on switch compared to repeat trials) (Stoet & Snyder, 2007), which is proposed to be due to

the additional resources required for reconfiguring task-sets. For example, updating parameters and resolving bottom-up interference from previous, but now irrelevant, task-sets (Vandierendonck, Liefooghe, & Verbruggen, 2010).

The Stroop task requires participants to respond to a colour word e.g., ("yellow") when presented in compatible (e.g., yellow) and incompatible (e.g., red) ink colours. Positive mood has not been found to affect performance on this task (e.g., Martin & Kerns, 2011), and it has been adapted into a set-switching paradigm by instructing participants to switch (i.e., on a trial by trial basis) between responding to the colour described by the word and to the colour of the ink. However, two studies have found that a positive (i.e., using guided memory retrieval and music) compared to a neutral induction did not result in any differences in switch costs on this paradigm (L. H. Phillips, Bull, Adams, & Fraser, 2002; Stafford, Ng, Moore, & Bard, 2010). Therefore, this suggests that positive mood may have no effect on flexibility in cognitive control, and in one of these studies (L. H. Phillips et al., 2002), a non-significant trend towards an increase in RT switch costs for positive mood.

One possible explanation for the lack of effect for positive mood on this set-switching paradigm was suggested by Dreisbach and Goschke (2004). It was proposed that positive affect may result in a novelty bias, which enhances flexibility specifically in relation to shifting attention towards novel sets. Therefore, null results in the Stroop set-switching paradigm may be because participants were required to repeatedly switch back and forth between recently suppressed task-sets. To test this proposition, a new attentional set-shifting paradigm was implemented, which aimed to examine the effect of positive affect on the specific processes underlying flexibility in cognitive control. Therefore, this involved a single switch in attentional-set (i.e., colour associated with a target stimulus), as opposed to the more complex and continuous switching that is required in the Stroop set-switching paradigm (i.e., switching back and forth between colour words and colour of stimulus).

Participants categorised a target stimulus that was presented simultaneously with a distractor stimulus (i.e., defined by pre-specified relevant and irrelevant colours). After a number of trials, the participants were instructed to switch to responding to a different colour target. There were two different switch conditions: a perseveration condition (target became a novel colour and distractor became the pre-switch target colour) and a distraction condition (target became the pre-switch distractor colour and distractor became a novel colour). It was argued that positive affect would induce a novelty bias, facilitating flexibility in cognitive control, but also increased distractibility. This was expected to be beneficial for the perseveration condition,

enabling a shift in attention to the novel target colour and reducing perseveration of the previous target (i.e., now the distractor), but detrimental for the distraction condition, as attentional capture by the novel distractor results in greater interference.

To examine the influence of positive affect on this paradigm, affective images were briefly presented prior to each trial. RT switch costs were found to be reduced in the perseveration condition for trials preceded by positive compared to neutral images. In contrast, switch costs were found to be increased in the distraction condition for trials preceded by positive compared to neutral images. Therefore, results were in line with Dreisbach and Goschke's (2004) predictions, such that positive affect resulted in an increased novelty bias, facilitating switching in the perseveration condition, but impairing switching in the distraction condition. This suggests greater flexibility in cognitive control, as a result of positive affect, may be beneficial or costly for performance, dependent on specific task demands. This is in line with Goschke and Bolte's (2014) suggestion of context-dependent costs and benefits for cognitive control within goal-directed behaviour (outlined above in Section 2.2.1.2).

2.2.2.2. Stability

Due to the antagonistic relationship between flexibility and stability in cognitive control (Goschke, 2000), and because positive mood has been suggested to be beneficial for flexibility, it may be suggested that this is detrimental to stability. To explore this, studies have examined the effect of positive mood on working memory storage capacity – the amount of information that is actively maintained at a given point in time (Cowan, 2010). Martin and Kerns (2011) found that a positive mood induction (i.e., using film clips) was detrimental to performance on a simple running span task – participants must recall the last six digits when presented with a string of digits sequentially. However, Yang, Yang, and Isen (2013) found that a positive (i.e., using presentation of gifts) compared to a neutral induction was beneficial for performance on a complex operation span task – participants required to recall words that were presented on a series of trials that also included an arithmetic problem, for which they were required to indicate whether a presented solution was correct.

Therefore, studies examining the influence of positive mood on these working memory tasks seem to produce contradictory results. One explanation for this may be the use of different paradigms (i.e., simple vs. complex working memory span tasks). These tasks rely, albeit to a different extent, on the same processes (i.e., active maintenance and updating in working memory) (Unsworth & Engle, 2007). However, complex memory span tasks have also been

suggested to involve cognitive flexibility (i.e., switching between processing/storage demands when performing concurrent tasks), which is not required in simple complex span tasks (Lépine, Bernardin, & Barrouillet, 2005). Therefore, positive mood may facilitate processes relating to flexibility within complex memory span tasks. Alternatively, another explanation may be that inconsistencies could be related to the different mood induction procedures used within studies (i.e., film clips vs. presentation of gifts).

The AX Continuous Performance Task (AX-CPT; Servan-Schreiber, Cohen, & Steingard 1996) was designed as a measure to assess the costs and benefits of stability in cognitive control. Participants are presented with a cue letter, followed by the presentation of a probe letter after a delay period. A target response is required on AX trials (probe X follows cue A), whilst a non-target response key is pressed on BX trials (probe X follows cue B), AY trials (probe Y follows cue A), and BY trials (probe Y follows cue B). AX trials are manipulated to occur on 70% of trials, creating a high expectation for a target response. Therefore, on AY trials, active maintenance of the cue A is detrimental to performance (i.e., associated with an incorrect response based on the expectation of an X probe). However, active maintenance of the B cue on BX trials is beneficial to performance (i.e., response preparation is biased towards a correct response). Therefore, by examining performance on these specific trials, the costs and benefits of stability in cognitive control can be examined.

The influence of positive affect on AX-CPT performance was first explored by Dreisbach (2006), in a study that required participants to respond to trials that were preceded by the brief presentation of positive or neutral affective images. Positive affect (compared to neutral affect) was found to result in improved performance (i.e., faster RTs and/or reduced error rates) on BX trials and attenuated performance on AY trials (i.e., slower RTs and/or increased error rates). This suggests that positive affect may attenuate the active maintenance of contextual information, which is beneficial for performance when representations need to be updated to a new goal unexpectedly (i.e., on AY trials), but is detrimental for performance when a goal, associated with actively maintained representations, is to be executed (i.e., BX trials). Furthermore, the results were more pronounced when the maintenance demands were increased (i.e., when extended delay period between cue and probe, and when distractor letters presented during this period).

Frober and Dreisbach (2014) also examined performance on the AX-CPT when neutral or positive affective images were briefly presented prior to each trial. Performance was found to be improved on AY trials for positive compared to neutral affect, which is in line with

Dreisbach's (2006) findings. However, no differences were found on BX trials, other than for a slight non-significant trend towards attenuated performance for positive affect. In addition, van Wouwe, Band, and Ridderinkhof (2011) examined AX-CPT performance following positive and neutral mood inductions (i.e., affective film clips that were watched prior to beginning the task). Positive mood was found to improve performance on AY trials, but again there were no significant differences on BX trials. This provides some evidence that effects of transient emotional responses (i.e. elicited by the brief presentation of affective images prior to trials) on this paradigm can be extended to more enduring positive mood states.

Another study conducted by Chiew and Braver (2014), also examined AX-CPT performance on trials that were preceded by positive and neutral images. However, a non-significant trend towards reduced performance for AY trials and enhanced performance on BX trials was found as a result of positive affect. This is the opposite pattern of results compared to other studies in this area (e.g., Dreisbach, 2006), and suggests that stability in cognitive control may in fact be slightly greater as a result of positive affect. However, this discrepancy may, in part, be due to methodological differences between studies. For example, Chiew and Braver (2014) did not display distractor stimuli in the delay period between cue and probes, but this was the case in Frober and Dreisbach's (2014) study. Therefore, this may have reduced the influence of positive affect on performance in AY and BX trials, presumably due to a reduction in the cue maintenance demands of the task.

2.2.3. Neurobiological Models

2.2.3.1. Prefrontal Cortex

Miller and Cohen (2001) stated that "cognitive control stems from the active maintenance of patterns of activity in the prefrontal cortex that represent goals and the means to achieve them. These provide bias signals to other brain structures whose net effect is to guide the flow of activity along neural pathways that establish proper mappings between inputs, internal states, and outputs needed to perform a given task". In other words, the prefrontal cortex maintains representations of task-relevant information, which biases down-stream processing (D'Esposito & Postle, 2015; Lara & Wallis, 2015). This is supported by the finding that disruption of prefrontal activity resulted in less activity in down-steam areas associated with the processing of particular visual stimuli (B. Miller, Vytlacil, Fegen, Pradhan, & D'Esposito, 2011). Furthermore, disruption of prefrontal activity was also found to have a detrimental effect

on performance in a working memory task, requiring the active maintenance of these stimuli (T. G. Lee & D'Esposito, 2013).

It has been suggested that dopamine activity in the prefrontal cortex plays a major role in cognitive control, which is based on findings from genetic studies demonstrating that performance on working memory tasks may be dependent on individual differences in dopamine activity (van Schouwenburg, Aarts, & Cools, 2010). For example, studies examining the Val158Met polymorphism of the COMT gene have found that Met allele carriers (associated with greater prefrontal dopamine) display enhanced performance on working memory tasks that require active maintenance compared to Val allele carriers (associated with lower prefrontal dopamine) (Aguilera et al., 2008). Furthermore, carriers of the Val allele also display greater prefrontal activity during these tasks compared to Met allele carriers, which is presumed to indicate less efficient processing (i.e., greater activity is required to meet task demands) (D. Dickinson & Elvevag, 2009). Therefore, this suggests that individual differences in dopamine activity in the prefrontal cortex may be related to the active maintenance of representations in working memory.

Pharmacological studies have also demonstrated that dopamine agonists/antagonists affect performance on working memory tasks (Luciana, Depue, Arbisi, & Leon, 1992; Mehta, Sahakian, McKenna, & Robbins, 1999), as well as the amount of prefrontal activity occurring during these (Willson, Wilman, Bell, Asghar, & Silverstone, 2004). However, the specific directional influence of dopamine agonists/antagonists has been demonstrated to be dependent on individual differences in baseline working memory capacity and prefrontal dopamine activity. For example, Kimberg, D'Esposito, and Farah (1997) found that a dopamine agonist (i.e., bromocriptine) resulted in enhanced performance on a working memory task only for those participants with a lower baseline capacity, whilst those with a higher capacity had attenuated performance. In addition, Gibbs and D'Esposito (2005) demonstrated that poorer performance on this task was related to greater prefrontal activity, suggesting that this increase in activity may reflect greater dopamine activity in the prefrontal cortex.

Two reviews have concluded that the effects of dopamine agonists/antagonists on working memory performance depends on individual differences in baseline dopamine activity in the prefrontal cortex (Cools & D'Esposito, 2011; van Schouwenburg, den Ouden, & Cools, 2010) Specifically, it is proposed that an inverted U-shaped relationship exists between baseline activity and the active maintenance of working memory representations, such that representations are stabilised at medium levels of dopamine, but become more vulnerable to

interference at levels that are either excessive or insufficient. Therefore, the effect of pharmacological manipulations on working memory performance may depend on baseline levels of dopamine activity, such that increases in activity for those with lower baseline levels may result in more robust stabilisation of representations and enhanced performance on working memory tasks. However, the opposite effect may be expected to occur for those with higher levels of prefrontal dopamine activity at baseline (i.e., in line with studies outlined in the previous paragraph).

The proposition that the effects of pharmacological manipulations on working memory performance may be dependent on baseline levels of prefrontal dopamine activity is also supported by studies combining genetic, pharmacological, and neuroimaging methodologies. For example, Mattay et al. (2003) demonstrated that a dopamine agonist (i.e., amphetamine) resulted in improved working memory performance, as well as reduced prefrontal activity (i.e., presumably reflecting enhanced efficiency), for carriers of the Val allele (associated with lower baseline prefrontal dopamine). However, the opposite effects were observed for carriers of the Met allele (associated with greater baseline prefrontal dopamine), such that performance was attenuated and prefrontal activity was increased (presumably reflecting decreased efficiency). This suggests that an increase in prefrontal dopamine activity may enhance the active maintenance of representations, but only for those individuals with lower levels of baseline activity. Therefore, it is important for studies examining the influence of positive mood on these processes to take into account individual differences relating to baseline levels of dopamine activity.

However, the effect of pharmacological manipulations on working memory may also depend on the specific type of dopamine activity that is elicited (Floresco, 2013). Firstly, activity can be described as either: i) tonic activity characterised by the constant, slow, and irregular firing of neurons, or ii) phasic activity characterised by transient “bursts” of high amplitude firing (Grace, 2016). Secondly, neurons can be classified into two primary sub-types: i) D1-like receptors (i.e., D1 and D5 neurons) that are described as allowing greater self-sustaining and recurrent activity, and are suggested to mediate tonic activity, or ii) D2-like receptors (i.e., D2, D3, and D4 neurons) that are described as being less resistant to outside activity, and are suggested to mediate phasic activity (J. D. Cohen, Braver, & Brown, 2002; Seamans & Yang, 2004). Based on this, animal studies have demonstrated that the effect of pharmacological manipulations on working memory depend on whether D1 mediated tonic activity or D2 phasic activity in the prefrontal cortex is affected.

These animal studies have demonstrated that prefrontal D1 activity is related to working memory performance in an inverted U-shape. For example, Zahrt, Taylor, Mathew, and Arnsten (1999) demonstrated that a dopamine agonist targeting D1 receptors (i.e., SKF 81297) injected into the prefrontal cortex of rats resulted in dose-related impairments in working memory tasks requiring active maintenance. This was such that performance was optimal at medium levels of D1 stimulation, and impaired for both higher and lower levels. Seamans, Floresco, and Phillips (1998) also demonstrated effects in line with these findings following the administration of a D1 antagonist (i.e., SCH 23390), whilst a D2 receptor antagonist (i.e., sulpiride) was found to have no effect. However, Druzin, Kurzina, Malinina, and Kozlov (2000) demonstrated that a D2 agonist (i.e., PPHT) and antagonist (i.e., sulpiride) attenuated and enhanced working memory performance respectively. These findings have led to the suggestion that D2 activity may have an antagonistic effect compared to D1 activity in the prefrontal cortex (Floresco, 2013).

Based on this, Durstewitz and Seamans (2008) proposed a "dual-state model" of the prefrontal cortex, in which an increase in tonic D1 activity facilitates the robust maintenance of working memory representations. However, an increase in phasic D2 activity is suggested to facilitate fast and flexible switching between these. This suggestion is supported by a study conducted by de Frias et al. (2010), which examined activity in the prefrontal cortex during a working memory task in relation to the COMT gene. Carriers of the Met allele (associated with greater prefrontal dopamine levels) were found to have greater sustained (i.e., tonic) activity in the prefrontal cortex during the delay phase of a working memory task (i.e., when active maintenance was required). However, carriers of the Val allele (associated with lower prefrontal dopamine levels) were found to have greater transient (i.e., phasic) activity during the updating phase of this task. Therefore, greater tonic D1 activity in the prefrontal cortex may mediate stability in cognitive control.

Braver and Cohen (2000) have suggested that phasic bursts of dopamine from the ventral tegmental area to the prefrontal cortex may act as an "updating mechanism", allowing new information entry into working memory. This is suggested to facilitate updating of representations, due to firing of D2 neurons in the prefrontal cortex (Cohen, Braver, & Brown, 2002). Therefore, the active maintenance of task-relevant representations may depend not only on the tonic state of the prefrontal cortex, but also the strength of phasic updating signals. Specifically, a strong updating signal would be required for new information to enter working memory in a state that was dominated by D1 activity. The concept of an updating mechanism

has been supported by a neuroimaging study conducted by D'Ardenne et al. (2012), which found a positive correlation between phasic activity in the ventral tegmental area and activity in the prefrontal cortex (as well as behavioural performance), during the encoding period of task-relevant cues on a working memory task.

2.2.3.2. Basal Ganglia

Alternatively, Frank and O'Reilly (2006) have argued that it is phasic dopamine activity in the basal ganglia that functions as an updating mechanism. It is suggested that bursts of dopamine activate a D1 mediated "Go Pathway", which disinhibits the tonic influence of the basal ganglia on the prefrontal cortex, allowing new task-relevant representations to enter working memory. This simultaneously suppresses a D2 "NoGo Pathway", which is activated by "dips" in dopamine activity, to prevent task-irrelevant representations from entering working memory. Within this model, it is suggested that D1 receptors have a low affinity for dopamine (Marcellino, Kehr, Agnati, & Fuxe, 2012), and, thus, only respond to phasic bursts of dopamine. However, D2 receptors have a higher affinity for dopamine, which allows these receptors to respond to tonic changes in dopamine levels (C. Clark & Dagher, 2014). Therefore, stability in this model relies on the strength of phasic bursts of dopamine to the basal ganglia, but also the tonic dopamine levels in this structure.

Traditionally, the basal ganglia has been associated with the flexible control of motor programs (McKenzie, Kemm, & Wilcock, 1984), with lesions being associated with symptoms of Parkinson's disease, such as motor rigidity (for a review see Lozza, Marier, and Baron, 2002). However, more recently, it has been suggested the basal ganglia may also be involved in the flexible control of cognitive programs (Frank, 2005), which is supported by findings that patients with Parkinson's disease have attenuated performance on set-shifting tasks compared to matched control participants (e.g., Woodward, Bub, & Hunter, 2002). Specifically, the symptoms of Parkinson's disease have consistently been related to the degeneration of dopamine neurons in the basal ganglia (A. Nelson & Kreitzer, 2014). This is supported by findings that detriments in set-shifting have been found to be greater for those patients abstaining from medication, compared to those taking dopamine agonists, in order to increase this activity in the basal ganglia (Cools, Barker, Sahakian, & Robbins, 2001).

There is less research examining the possibility of an inverted U-shape relationship between D2 activity specifically in the basal ganglia and flexible switching (cf. D1 activity in the prefrontal cortex and active maintenance) of representations. However, there is some evidence

to suggest that this may be the case. For example, Samanez-Larkin et al. (2014) examined performance on a set-switching task, and found that switch costs were reduced following the administration of a dopamine agonist (i.e., amphetamine). However, those with lower levels of baseline D2 dopamine release in the basal ganglia were found to have greater reductions in switch costs. This is in line with findings from studies outlined in Section 2.1.3.4, which demonstrated an inverted U-shaped relationship between baseline EBR and cognitive flexibility on more complex cognitive tasks (i.e., those assessing divergent thinking) (Chermahini & Hommel, 2010, 2012). However, the relationship between D1 activity in the basal ganglia and flexibility in cognitive control is currently unclear at present.

2.2.3.3. Influence of Positive Affect

The suggestion of an interaction between the basal ganglia and the prefrontal cortex in mediating cognitive control is supported by neuroimaging studies. For example, it has been demonstrated that there is an increase in functional connectivity between the basal ganglia, prefrontal cortex, and stimulus-specific visual processing areas during attentional set-switching tasks (van Schouwenburg et al., 2010). This is qualified by findings that this coincides with a decrease in connectivity between the basal ganglia and fronto-parietal non-specific visual processing areas (Bloemendaal et al., 2013). In addition, a recent pharmacological neuroimaging study conducted by Samanez-Larkin et al. (2014) examined set-switching performance following the administration of a D2 dopamine agonist. Within this study, switch costs were found to be reduced compared to a placebo condition, and greater flexibility was also found to be positively related to D2 receptor availability in the prefrontal cortex, basal ganglia, and parietal areas.

Therefore, it may be suggested that positive affect may influence cognitive control processes by moderating dopamine levels in the basal ganglia and prefrontal cortex. One mechanism may be suggested to be a decrease in tonic D1 activity and/or an increase in phasic D2 activity in the prefrontal cortex. This would attenuate active maintenance of representations and facilitate updating, resulting in attenuated stability as demonstrated by studies outlined in Section 2.2.2.2, which examined the influence of positive affect on the AX-CPT (e.g., Dreisbach, 2006). Another possible mechanism could be an increase in tonic D2 activity in the basal ganglia and/or an increase in phasic D1 activity. This would also facilitate updating and enhanced switching of attention between representations, resulting in greater flexibility as demonstrated by studies that were also outlined in Section 2.2.2.1, which examined the

influence of positive affect on the set-shifting paradigm (e.g., Dreisbach & Goschke, 2004). These mechanisms have also been suggested to underlie the influence of positive affect on cognitive control processes in a recent review (Goschke & Bolte, 2014).

2.2.3.4. EBR

In Section 2.1.3.3, it was suggested that EBR may reflect greater dopamine activity in the basal ganglia, which was based on evidence from clinical studies of patients with disorders affecting activity in this area. Pharmacological animal studies have led to the suggestion that EBR may specifically reflect greater D2 dopamine activity in the basal ganglia. This is based on findings that EBR increases following the administration of a selective D2 agonist (i.e., 4-propyl-9-hydroxynaphoxazine or PHNO), but decreases following the administration of selective D2 antagonists (i.e., remoxipride and sulpiride) (Elsworth et al., 1991; Lawrence & Redmond, 1991). These studies also found that the pre-treatment administration of these D2 antagonists blocked the expected increase in EBR following the D2 agonist. However, it should be noted that a more recent study, conducted by Kotani et al. (2016), did not replicate previous findings, and instead demonstrated that the administration of the same dopamine agonist (i.e., PHNO) reduced EBR.

Interestingly, pharmacological animal studies have also found that EBR increases following the administration of D1 agonists (i.e., dihydrexidine, SKF 81297, and SKF 82958) (Elsworth et al., 1991; Kleven & Koek, 1996; Kotani et al., 2016). Although one study found that the D1 agonist SKF 38393 resulted in a decrease in EBR (Kleven & Koek, 1996), Elsworth et al. (1991) suggests that this may be because SKF 38393 is only a partial agonist, and argues that results are more reliable using full agonists. Again, D1 antagonists (i.e., SCH 23390) have been found to reduce EBR and pre-treatment administration has been demonstrated to block the effects of D1 agonists (Elsworth et al., 1991). Furthermore, Elsworth et al. (1991) also found that whilst the effects of D1 agonists were only blocked by the pre-treatment of D1 specific antagonists (and not those antagonists targeting D2 receptors), D2 agonists were only blocked by the pre-treatment administration of D2 antagonists. Therefore, this suggests that EBR may reflect greater D1 and D2 activity in the basal ganglia, and that these effects may occur independently.

The suggestion that pharmacological manipulations targeting D1 and D2 receptor subtypes may have independent effects on EBR is supported by a separate study that was conducted by Jutkiewicz and Bergman (2004). This study demonstrated that the effect of a D1 agonist (i.e.,

6-Br-APB) on EBR was blocked by pre-treatment administration of several D1 antagonists (i.e., SCH 39166 and SKF 83959). However, the effect of the D1 agonist was not blocked by the administration of a D2 antagonist (i.e., haloperidol). Importantly, this study also found that the pre-treatment administration of a D2 agonist (i.e., PHNO) did in fact block the effects of the D1 agonist on EBR. Therefore, this suggests that pharmacological manipulations targeting D1 and D2 receptor subtypes may independently modulate EBR, but also that the effect of one of these subtypes on EBR may inhibit the effect of the other (Jongkees & Colzato, 2016). This is in line with the suggestion of complimentary, but distinct, D1- and D2-mediated "Go" and "NoGo Pathways" in the basal ganglia (Frank & O'Reilly, 2006).

Whilst pharmacological manipulations targeting D1 and D2 activity may both influence EBR, it is suggested that EBR at rest (i.e., assessed at baseline or in the absence of a manipulation) may primarily reflect D2 activity. This is based on findings from a neuroimaging study conducted by Groman et al. (2014), which demonstrated that EBR is positively correlated with only D2 (and not D1) receptor density when assessed at baseline. However, this study also demonstrated that EBR was increased following the administration of both a D1 (i.e., dihydrexidine) and D2 agonist (i.e., PHNO), but that this increase was positively correlated with only D2 receptor density at baseline. This suggests that the increase in EBR following both D1 and D2 agonists was greatest for those individuals with a lower baseline D2 receptor density. The supports the suggestion that baseline EBR may primarily reflect the activity of D2 receptors, and that the influence of pharmacological manipulations on EBR may depend on these individual differences at baseline.

The studies described so far in this sub-section have been conducted using animal samples, and there is only limited pharmacological research conducted with human participants. The non-selective dopamine agonist apomorphine has been demonstrated to increase EBR in humans (Blin, Masson, Azulay, Fondarai, & Serratrice, 1990), as has amphetamine (Strakowski, Sax, Setters, & Keck, 1996). However, selective D2 agonists and antagonists have been found to have no effect on EBR (Depue, Luciana, Arbisi, Collins, & Leon, 1994). Despite this, a recent study conducted by Cavanagh, Masters, Bath, and Frank (2014) demonstrated that a D2 agonist (i.e., cabergoline) did modulate EBR, but that this was dependant on baseline EBR levels. This was such that whilst there was an increase in EBR following administration of the D2 agonist for those with a lower baseline EBR, there was a decrease for those with a higher baseline EBR. Therefore, the effect of pharmacological manipulations on EBR may be non-linear and

follow an inverted U-shape (for agonists), which is dependent on baseline levels of D2 activity in the basal ganglia.

Dreisbach et al. (2005) examined the effect of baseline EBR on Dreisbach and Goschke's (2004) set-shifting paradigm – previously used to demonstrate that positive affect resulted in greater flexibility in cognitive control (specifically in relation to an increased novelty bias) (Dreisbach & Goschke, 2004). In this study, participants with a higher EBR were found to have greater switch costs in the perseveration condition and lower switch costs in the distraction condition, in comparison to those participants with a lower EBR. This was the same pattern of results as was observed following the induction of positive (compared to neutral affect) in the previous study (i.e., Dreisbach & Goschke, 2004). This suggests that a higher EBR and positive affect may both result in greater flexibility in cognitive control (at the cost of increased distractibility). Therefore, although this does not directly demonstrate that D2 activity in the basal ganglia underlies findings that positive affect results in greater flexibility in cognitive control, it suggests that this may be the case.

In the same study, Dreisbach et al. (2005) also examined performance on this set-shifting paradigm in relation to different genetic polymorphisms associated with dopamine activity, including the Val158Met polymorphism of the COMT gene and the exon III polymorphism of the DRD4 gene. Although performance was not found to be influenced by either polymorphism, an interaction was observed between the DRD4 gene and baseline EBR. This was such that results for individuals with a higher EBR (i.e., reduced switch costs in the perseveration condition and increased switch costs in the distraction condition) were more pronounced for those who were carriers of the 7-repeat allele DRD4 polymorphism, which is associated with greater D2-like activity in the basal ganglia. However, whilst other studies have replicated the main effect of EBR on performance on this paradigm (Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011), an interaction with the DRD4 polymorphism was not found to reach significance (Muller, Dreisbach, Brocke, et al., 2007).

These findings suggest that those individuals with greater baseline D2 activity in the basal ganglia (i.e., as reflected by a greater EBR at rest) demonstrate greater flexibility in cognitive control. Furthermore, a recent study conducted by Rac-Lubashevsky, Slagter, and Kessler (2017) has demonstrated that EBR assessed during task performance is related to more flexible switching. A novel task was used to assess flexibility in cognitive control, which was referred to as the "reference-back task". Participants completed two different types of trials that involve being presented with a stimulus, which are referred to as reference or comparison trials, and

are indicated by different colour stimuli. Each trial requires the participant to respond as to whether the presented stimulus is the same/different to the most recently presented reference stimulus. Therefore, this allows the separation of processes involved in the maintenance of contextual information (i.e., comparison trials), and updating of representations (i.e., reference trials). It was found that EBR during reference trials was greater than comparison trials, suggesting that EBR is related to flexible updating and shifting of representations.

2.2.4. Interim Summary

Cognitive control in goal directed behaviour refers to the antagonistic balance between flexibly switching between goals (updating information in working memory and shifting focus to new representations) and shielding goals from distraction (stabilisation and maintenance of contextual information in working memory) (Goschke, 2000). Early experimental work, using working memory and set-switching paradigms, failed to find consistent evidence that positive affect influenced the balance between flexibility and stability in cognitive control (e.g., Phillips et al., 2002; Martin & Kerns, 2011; Yang et al., 2013). However, more recent work has used new paradigms that allow a more fine-grained examination of these processes. Notably, Dreisbach and Goschke (2004) developed a set-shifting paradigm to demonstrate that positive affect promotes flexible switching (at the cost of increased distractibility), specifically through a novelty bias. In addition, the AX-CPT has been used to demonstrate that positive affect also attenuates stability in cognitive control, in terms of reducing the active maintenance of contextual information (at the cost of increased perseveration).

Neurobiological models suggest that cognitive control is mediated by dopamine activity in the prefrontal cortex and/or the basal ganglia. Specifically, it is suggested that a state dominated by tonic D1 activity in the prefrontal cortex results in the active maintenance of contextual information in working memory (Durstewitz & Seamans, 2008). However, phasic bursts of activity from the ventral tegmental area may facilitate updating of new information entry by shifting this balance towards a state dominated by D2 activity (Braver & Cohen, 2000). This is supported by findings of an inverted U-shape relationship between baseline prefrontal D1 activity and performance on working memory tasks (e.g., Cools & D'Esposito, 2011)). Alternatively, updating may occur due to phasic bursts of dopamine activity from the substantia nigra, which projects to the basal ganglia. This is proposed to activate a D1-mediated "Go Pathway" and supress a D2-mediated "NoGo Pathway", allowing new information to enter working memory (Frank & O'Reilly, 2007). There is also evidence of an inverted U-shape

relationship between baseline D2 activity in the basal ganglia and performance on set-shifting tasks (Floresco, 2013).

Neurobiological mechanism suggested to underlie the balance between flexibility and stability in cognitive control overlap with those proposed by the neuropsychological theory of positive affect (Ashby et al., 1999). Based on these models, positive affect may be suggested to: i) decrease tonic D1 activity and/or increase phasic D2 activity in the prefrontal cortex resulting in attenuated stability; ii) increase tonic D2 activity and/or increase phasic D1 activity in the basal ganglia, resulting in greater flexibility. There is somewhat inconsistent evidence in relation to the specific activity reflected by EBR, as manipulations increasing activity of D1 and D2 receptors (associated with increases in tonic dopamine activity in the prefrontal cortex vs. basal ganglia respectively) have both been demonstrated to increase EBR (e.g., Elsworth, 1991). However, when assessed at rest, EBR has been suggested to primarily reflect D2 activity in the basal ganglia (Jongkees & Colzato, 2016). Therefore, findings that those with a higher baseline EBR demonstrate greater flexibility on the set-shifting paradigm (e.g., Dreisbach et al., 2005) may suggest that the influence of positive affect on flexibility may be related to an increase in dopamine activity in the basal ganglia.

2.3. Appetitive Motivation

This section begins by defining appetitive motivation and outlining the role of an appetitive motivational system in goal-directed behaviour. An overview is then provided of positive affect that is high in appetitive motivation, and contrasted with positive affect that is low in appetitive motivation. This is followed by a description of the motivational intensity model of positive affect (Gable & Harmon-Jones, 2010), which suggests that motivational intensity may moderate the influence of positive affect on cognition. Supporting evidence for this account is provided, in relation to attentional and cognitive processes. This is followed by an overview of the reward-as-motivation hypothesis (Goschke & Bolte, 2014), which offers an alternative explanation for some of these findings. Finally, the neurobiological basis of appetitive motivation will be outlined, focusing on dopamine activity and evidence that this may be lateralised to frontal areas in the left hemisphere of the brain.

2.3.1. Motivation

In Section 2.1.1.2, affect was described in terms of two dimensions: valence and activation (Russell, 1980). More recently, it has been suggested that motivation may also be an important additional dimension of affect (Harmon-Jones, Harmon-Jones, & Price, 2013). Although it is suggested that positive affective states are generally associated with the motivation to approach a stimulus or situation (i.e., "appetitive motivation) and negative affective states are generally associated with the motivation to withdraw from a stimulus or situation (i.e., "withdrawal motivation") (Watson, 2002), this is not always the case. For example, anger is an affective state with a negative valence, but it is also associated with approach motivated action (Carver & Harmon-Jones, 2009). Furthermore, whilst activation, in terms of the stimulation of the sympathetic nervous system (Bradley & Lang, 2007), may be a proxy for motivational intensity, this is considered to be separable, in terms of involving implications for action (as opposed to only biological readiness). For example, amusement is a highly activated state, but is not associated with approach behaviour (Gable & Harmon-Jones, 2010).

2.3.1.1. Drive Theory

To survive and procreate, Craig (1918) suggested that organisms are directed towards certain biological stimuli that can be termed "appetitive" (derived from the word "appetite") (e.g., food and water, and sex), but directed away from stimuli termed "aversive" (e.g., injury). This allows an organism to meet its biological needs and to achieve homeostasis – the maintenance of a constant internal environment (Cannon, 1929), and includes processes such as the regulation of blood sugar levels, body temperature, water content of the body, etc. Based on this, Woodworth (1958) defined motivation as the drive that an organism experiences, in terms of becoming active and striving for or avoiding these biological stimuli. Expanding on this, Hull (1943) emphasised the role of psychological drives (e.g., hunger, thirst, sexual desire, pain, etc.) in motivation. These were proposed to arise from the deprivation of biological needs (e.g., food, water, sex, avoidance of injury, etc.), and result in the organism becoming "energised" to reduce psychological drives.

Drive reduction was suggested to be reinforcing, which is grounded in the work of Thorndike (1912), who suggested that behaviour could be learnt through associations being made between stimuli and responses. This was expanded by Skinner (1938, 1958), who demonstrated that associations were strengthened (or reinforced) when followed by rewards – appetitive stimuli (e.g., food) or omission of aversive stimuli (e.g., painful electric shock). Based on this, Hull (1943) proposed that drive reduction led to the development of learned patterns of behaviour.

Later, Hull (1951) introduced the concept of “secondary drives”, to account for drives that are not directly associated with biological stimuli (e.g., money). Based on the work of Pavolv (1927), it was suggested that innate psychological drives occurring in response to biological stimuli can be conditioned to occur with neutral stimuli or “cues” (e.g., money leads to reduction of hunger), when these are repeatedly paired, resulting in the development of secondary drives.

2.3.1.2. Role of Emotion

The role of emotion in motivation was introduced by Mowrer (1960). An increase in psychological drive was suggested to occur in response to the innate emotional response of fear, leading the organism to engage in behaviours to escape the eliciting stimulus (e.g., running away from the source of a painful shock). It was suggested that fear would eventually become conditioned to cues, and the organism would eventually engage in behaviour to avoid these (e.g., avoiding being in the environment where the painful shock occurred). Furthermore, it was argued that motivation can occur not only as part of drive reduction, but also due to a decrease in psychological drives. This was suggested to result in the innate emotional response of hope, motivating the organism to stay in the presence of the eliciting stimulus (e.g., staying close to a source of food). This emotional response was also argued to eventually become paired with cues, resulting in approach behaviour towards these (e.g., preferring to be in the room where the food was received).

2.3.1.3. Motivational Systems

This biphasic organisation of motivational systems is in line with Schneirla's (1959) suggestion that there are two primary categories of innate behaviour: “approach” behaviour, which moves an organism closer to an eliciting stimulus (e.g., when acquiring food, obtaining shelter, and mating); and “withdrawal” behaviour, which moves an organism away from an eliciting stimulus (e.g., during defence, huddling, and fleeing). The role of emotion in these two systems has also been emphasised by Konorski (1969), who argued that innate reflexive responses to biological stimuli could be organised into two categories. “Preservative” behaviours (e.g., ingestion, copulation, and nurture of progeny) were suggested to be associated with positive feelings, such as sexual passion, joy, and nurturance. However, “protective” behaviours (e.g., escape and rejection of noxious agents) were suggested to be associated with negative feelings, such as fear and anger. Similar biphasic systems have also been proposed elsewhere, such as

by Dickinson and Dearing (1979), who describe these as eliciting “attractive” and “aversive” behaviours.

Following on from this work, Gray (1976, 1982, 1991) proposed the reinforcement sensitivity theory, which has subsequently received a number of revisions (Corr & McNaughton, 2008; Gray & McNaughton, 2000; McNaughton & Corr, 2004). It is currently theorised that there are three motivational systems that guide motivated or goal-directed behaviour. The behavioural activation system (BAS) is suggested to respond to appetitive stimuli and generate the hopeful emotion of anticipatory pleasure, motivating the individual to engage in approach behaviour towards the eliciting stimulus. The fight-flight-freeze system (FFFS) is suggested to be responsive to aversive stimuli and generate the emotion of fear, which motivates the individual to engage in avoidance or escape behaviours away from the stimulus. The third system is called the behavioural inhibition system (BIS), which responds to conflict and generates the emotion of anxiety. It functions to resolve conflict between or within the BAS and FFFS (Rutherford & Lindell, 2011).

Depue and Collins (1999) have proposed a similar system to the BAS, which is responsive to appetitive or “incentive” stimuli (a term used in this theory, but usually reserved for animal models). This is referred to as the behavioural facilitation system. Multiple stages are suggested to be involved in responding to incentive stimuli: a terminal stage referred to as “consummatory” (derived from the term “consummation”), which reflects responses occurring upon direct interaction with the eliciting stimulus, and an “appetitive” stage described as involving responses that are “preparatory” (Blackburn, Phillips, & Fibiger, 1989) or “anticipatory” (Ikemoto & Panksepp, 1999), in terms of increasing the proximity of the organism to the stimulus. These stages have been associated with different types of motivational feelings in animal models, such that the consummatory stage is suggested to involve “liking” responses (described as a pleasurable satisfaction), whilst the appetitive stage is suggested to involve the primary experience of “wanting” responses (i.e., described as an intense desire) (Berridge & Robinson, 1998).

Therefore, Depue and Collins (1999) suggest that a human behavioural facilitation system generates subjective “wanting” responses, which are motivational feelings (i.e., desire, craving, and potency), as well as the affective feelings of excitement, euphoria, elation, and enthusiasm. This is argued to be distinct from the calm pleasure that is elicited during consummatory “liking” responses, which does not include feelings of motivation, and is described as being associated with the affective feelings of gratification, satisfaction, enjoyment, and contentment.

In Section 2.1.1.2, the structure of affect was described as a circumplex, with a horizontal axis representing valence and a vertical axis representing activation, such that there are four primary segments into which affective states can be categorised (see Figure 2.1). From this model, it can be suggested that the affective feelings associated with appetitive motivation are located in the activated pleasure quadrant of this model, whilst affective feelings associated with consummation are likely to be located in the deactivated pleasure quadrant.

2.3.2. Influence on Cognition

2.3.2.1. The Motivational Intensity Model

The studies reviewed in previous sections suggest that positive mood results in broader and more flexible cognition. However, the motivational intensity model of positive affect (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognition depends on the intensity of approach motivation. Intensity is defined as the strength of motivation, such that positive mood states can be described as being either high or low in appetitive motivation. However, motivational intensity is considered to be a separate dimension to affect, in addition to the dimensions of valence and activation. The majority of affective states that are high in appetitive motivation are also of a positive valence and high in activation (Bradley & Lang, 2007), although this is not always the case. For example, anger has a negative valence, but this has been described as being high in approach motivation (Carver & Harmon-Jones, 2009). Furthermore, whilst amusement is a positive affective state that is high in activation, this is suggested to be unlikely to elicit approach motivation (Fredrickson & Branigan, 2005).

The suggestion that positive mood states can vary in motivational intensity is in line with previous models of emotion. For example, Panksepp (1998) described a "PLAY" system that is involved in the joyous experience of developing knowledge and social bonds, and a separate "SEEKING" system that energises the individual to seek goods from the environment. Other models have drawn distinctions between positive affect experienced in "pre-goal" situations, as an individual moves towards an appetitive goal, and in "post-goal" situations, following the acquisition of the goal (Davidson, 1998). These positive states are described as being generally associated with low and high levels of activation respectively. Therefore, a "PLAY" system mediating "post-goal" positive affect is in line with Depue and Collin's (1999) suggestion of the consummatory stage of appetitive behaviour, whilst a "SEEKING" system mediating "pre-goal" positive affect is in line with "wanting" responses occurring during appetitive motivation.

Drawing on these models of emotion, the motivational intensity model suggests that positive affect that is low in appetitive motivation activates the "PLAY" system. This is argued to result in broader cognition, facilitating behaviour involved in the building of personal resources (Fredrickson, 1998). This is in line with Carver's (2003) suggestion that positive affect serves as a signal that goal progress is progressing better than expected, allowing individuals to "coast", and engage in new behaviours when opportunities arise. Based on this idea, Gable and Harmon-Jones (2010) propose that only positive affect that is low in appetitive motivation functions to signal a safe environment, facilitating broader cognition. Alternatively, positive affect that is high in appetitive motivation is suggested to promote tenacious goal-pursuit. Therefore, this is argued to activate the "SEEKING" system, which results in narrower cognition, in order to facilitate goal related behaviour. This is proposed to allow individuals to shut out irrelevant stimuli, perceptions, and cognitions as they approach appetitive stimuli.

2.3.2.2. Attentional Scope

As outlined in Section 2.1.2.1, previous studies have found that attentional scope is broader following a positive mood induction. This has been demonstrated using variations of the Navon (1977) letter task, which involves participants being presented with a large shape or letter that consists of smaller shapes of letters (i.e., global vs. local features). Positive affect has been demonstrated to result in a more global focus of attention, such that participants are more likely to identify targets as being most similar to the larger shapes/letters (e.g., Fredrickson & Branigan, 2005). However, Gable and Harmon-Jones (2008b) have examined performance on this task following positive mood inductions that were either high or low in appetitive motivation (induced using film clips of desserts vs. amusing animals respectively). It was found that positive affect high in appetitive motivation resulted in a more local (or less global) focus of attention, in comparison to positive affect that was low in appetitive motivation.

In a second experiment, Gable and Harmon-Jones (2008b) examined the influence of positive affect that was high in appetitive motivation on another version of the Navon (1977) letter task that required participants to identify shapes/letters by either global or local features. Performance for positive affect high in appetitive motivation was compared to neutral affect (induced using images of desserts vs. rocks prior to each trial). For positive affect high in appetitive motivation, a narrower attentional scope was observed (i.e., RTs were faster for local features, but slower for global features). In addition, a further experiment conducted by these authors demonstrated that participants who were told that they would be able to eat the desserts

at the end of the experiment, presumably increasing the intensity of appetitive motivation, had an even narrower attentional scope compared to those who simply viewed the images of these desserts.

Domachowska et al. (2016) attempted to replicate Gable and Harmon-Jones' (2008b) findings in two experiments. Performance on the second version of Navon (1977) letter task described above was compared for positive affect high in appetitive motivation and neutral affect. Attentional scope was narrower (i.e., RTs were slower on global trials) for positive affect that was high in appetitive motivation, which replicates the earlier findings. These authors also compared performance on this task for both positive affect that was high and low in appetitive motivation and neutral affect. Again, attentional scope was found to be narrower for positive affect that was high in appetitive motivation compared to neural affect. A more global bias was expected when comparing positive affect that was low in appetitive motivation to positive affect that was high in appetitive motivation, which would have been in line with earlier findings. However, RTs on both global and local trials were found to be slower, suggesting that this was generally detrimental to performance.

Inconsistencies between these studies may be due to different stimuli used to induce positive affect low in appetitive motivation. Domachowska et al. (2016) used images of animals and flowers, whilst Gable and Harmon-Jones (2008b) used amusing film clips. The stimuli used in the former study may have had some appetitive properties, as "cute" animals and babies are suggested to be likely to induce appetitive motivation and approach behaviour (Gable & Harmon-Jones, 2010). Therefore, these images may not have elicited positive affect that was predominantly low in appetitive motivation as effectively as the amusing stimuli used in the latter study. This is further supported by the fact that Domachowska et al. (2016) found that global bias scores (RTs for global targets subtracted from local targets) were reduced for positive affect that was low in appetitive motivation when compared to neutral affect, but increased when compared to positive affect that was high in appetitive motivation.

In fact, Nittono, Fukushima, Yano, and Moriya (2012) have examined the effect of viewing images of baby compared to adult animals on the Navon (1977) letter task. The images of baby animals in this study were rated as "cuter" than the images of adult animals, and were demonstrated to result in a reduced global bias score (i.e., more local focus). Therefore, this suggests that these images may be likely to induce appetitive motivation or approach behaviour, and result in a narrower scope of attention. Furthermore, the presentation of other appetitive stimuli has also been found to result in similar findings on this paradigm. For

example, in two separate experiments, Hicks, Friedman, Gable, and Davis (2012) found that the presentation of the images of alcohol resulted in a reduced global bias (i.e., more local focus) for those who reported a greater motivation to drink alcohol. However, neutral images of rocks were not found to effect global bias.

Another study, conducted by (Gable & Harmon-Jones, 2011), examined the effect of monetary incentives on the Navon (1977) letter task. This was suggested to allow greater validity in examining the effect of "pre-goal" positive affect high in appetitive motivation and "post-goal" positive affect low in appetitive motivation, compared to previous work examining the effect of presenting images to induce these distinct states. Positive affect high in appetitive motivation was induced by presenting cues prior to trials, which indicated that a monetary incentive was available, based on performance. In line with previous research, a global bias was reduced on trials offering incentives, which suggests a narrower attentional scope. Feedback was provided when an expected incentive was obtained, which was used to induce positive affect that was low in appetitive motivation. This was found to result in a greater global bias, which suggests a broader attentional scope.

2.3.2.3. Cognitive Control

Positive affect has also been demonstrated to moderate the balance between flexibility and stability in cognitive control – outlined in Section 2.2.2. Specifically, using a set-shifting paradigm, positive affect has been found to enhance flexibility in cognitive control (Dreisbach & Goschke, 2004). This is in terms of positive affect decreasing perseveration, but also increasing distractibility, which is suggested to be due to an increased novelty bias. Furthermore, positive affect has also been found to result in reduced stability in cognitive control, as demonstrated on the AX-CPT. Performance has been found to be enhanced on this task when the correct response requires contextual information to be updated unexpectedly (i.e., flexibility) on AY trials. However, performance has been found to be attenuated when a correct response is associated with contextual information being continuously maintained in working memory (i.e., stability) on BX trials (e.g., Dreisbach, 2006).

The motivational intensity model (Gable & Harmon-Jones, 2010) proposes that positive affect low in appetitive motivation occurs during the "post-goal" period of goal-directed behaviour. This is suggested to facilitate engagement in new opportunities, allowing the organism to build upon personal resources. Greater flexibility (reduced stability) in cognitive control may be suggested to be beneficial for engaging in new opportunities and goals, in terms of attenuating

the perseveration of currently active representations for accomplished goals, and facilitating switching to new representations. In contrast, positive affect high in appetitive motivation is suggested to occur during the "pre-goal" period, and promote focus on the pursuit of active goals. Therefore, greater stability (reduced flexibility) could be beneficial for focused goal-pursuit, in terms of promoting the active maintenance of representations relating to the current goal, and reducing interference from goal-irrelevant stimuli.

Liu and Wang (2014) examined the influence of positive affect that was high and low in appetitive motivation on Dreisbach and Goschke's (2004) set-shifting paradigm. Prior to each trial, participants were presented with images of either: desserts (positive affect high in appetitive motivation), landscapes (positive affect low in appetitive motivation), or household objects (neutral affect). Compared to neutral affect, positive affect low in appetitive motivation was found to result in enhanced perseveration and increased distraction, suggesting greater flexibility in cognitive control. However, the opposite pattern of results was found for positive affect high in appetitive motivation, suggesting reduced flexibility. These results are in line with the suggestion that appetitive motivation does moderate the influence of positive affect on cognitive control, such that only positive affect low in appetitive motivation results in greater flexibility, whilst positive affect high in appetitive motivation may have the opposite effect and reduce flexibility.

Wacker (2017) examined the moderating role of appetitive motivation in relation to the influence of positive affect on performance on the AX-CPT. Positive mood was induced prior to the task using mental imagery of either: future goals/events (high in appetitive motivation), or a close family member/friend (low in appetitive motivation). This was then followed by participants watching emotional film clips of a similar content, prior to the task being completed. An index of stability was calculated (RTs on AY trials subtracted from average on BX and BY trials). This was found to be greater for positive affect that was low compared to high in appetitive motivation, suggesting that stability in cognitive control was greater for positive affect that was low in appetitive motivation. Although this suggests that appetitive motivation moderates the influence of positive mood on cognitive control, this was not in the expected direction.

However, the mood induction procedure used by Wacker (2017) was not demonstrated to result in the expected changes in positive affect. Although ratings of adjectives used to assess positive affect low in appetitive motivation (i.e., cozy, comfortable, liked, and secure) were increased following only the low appetitive induction, adjectives used to assess positive affect high in

appetitive motivation (i.e., pleasant, anticipation, eager, inspired, driven, and confident) were increased following both of the inductions. Therefore, these inductions may not have appropriately induced mood states that were either high or low in appetitive motivation. Furthermore, whilst significant differences on the composite stability index were found following these mood inductions, statistics for pertinent (AY and BX) trials are not reported independently. Although, these can be seen to numerically follow the same pattern of results as the stability index, it is unclear whether these reach significance.

2.3.2.4. The Reward-as-Motivation Hypothesis

An alternative account of the influence of appetitive motivation on cognitive control is provided by the reward-as-motivation hypothesis. This suggests that rewards (i.e., appetitive goals) enhance an individual's motivation to engage in effortful control (Aston-Jones & Cohen, 2005). Greater effortful control is suggested to optimise performance and increase the likelihood of the individual being able to obtain the reward. This is proposed to occur due to enhanced task preparation, which facilitates the organisation of attention, perception, and action selection systems (Stephen Monsell & Driver, 2000). Drawing on this, Braver (2012) suggests that rewards activate a proactive (i.e., stable) control mode, allowing the continuous and sustained maintenance of relevant contextual information. This is held in the anticipation of interference, and prevents goal-irrelevant information from being able to capture attention, thus optimising task performance.

The reward-as-motivation hypothesis is supported by studies finding that performance-based incentives result in reduced flexibility (greater stability) in cognitive control. For example, Muller, Dreisbach, Goschke, et al. (2007) found that monetary incentives produced the opposite pattern of results compared to those previously found to occur for positive affect (presumably low in appetitive motivation) (i.e., Dreisbach & Goschke, 2004), such that flexibility was reduced (i.e., performance was enhanced in the perseveration condition, but attenuated in the distraction condition). In addition, monetary incentives have also been found to result in the opposite pattern of results on the AX-CPT compared to those previously observed for positive affect (e.g., Dreisbach, 2006). For example, performance has been found to be attenuated on AY trials, which require flexibility (Locke & Braver, 2008), but enhanced on BX trials, requiring stability in cognitive control (Chiew & Braver, 2014).

Within this account, rewards are suggested to signal that an exploitative mode of processing is required. However, positive affect that is unrelated to a task or goal is suggested to serve a

different function, in terms of signalling that a more explorative mode of processing is required (Chiew & Braver, 2011). Based on this, the reward-as-motivation hypothesis suggests that positive affect activates a reactive (i.e., flexible) control mode, which facilitates exploration. This is because goal-relevant representations are not being continuously maintained, allowing bottom-up information to capture attention more easily (Braver, 2012). Therefore, unlike the motivational intensity model, this account suggests that all types of positive affect, as long as this occurs independently to task performance, results in greater flexibility in cognitive control (i.e., a reactive control mode).

This is supported by a study conducted by Frober and Dreisbach (2014), which examined performance on the AX-CPT for trials that were preceded by cues indicating performance-based monetary incentives were available, or positive images to induce positive affect that was independent to the task. In line with previous findings, monetary incentives were found to result in more stability in cognitive control, as demonstrated by attenuated performance on AY trials, but enhanced performance on BX trials. However, the opposite pattern was observed for positive affect that was unrelated to the task, suggesting reduced stability (increased flexibility). This was such that performance on AY trials was enhanced, whilst performance on and BX trials was attenuated. Therefore, this is in line with the reward-as-motivation hypothesis, in terms of demonstrating opposite effects for performance-based incentives and positive affect that is independent to performance.

However, Frober and Dreisbach's (2014) findings are not inconsistent with the motivational intensity model of positive affect. Specifically, it could be assumed that the cues indicating the availability of monetary incentives (a Euro sign in this study) may have induced positive affect that was high in appetitive motivation, whilst the positive images (used to in induce positive affect that was independent to the task) may have induced positive affect that was low in appetitive motivation. In fact, findings from all of the studies that are presented above in support of the reward-as-motivation hypotheses, may also be in line with the motivational intensity model, if monetary incentives are assumed to induce positive affect that is high in appetitive motivation. However, the reward-as-motivation hypothesis cannot account for some of the findings that have been produced in relation to the motivational intensity model of positive affect.

For example, the study conducted by Liu and Wang (2014) demonstrated that positive affect that was unrelated to the set-shifting task had a differential effect on cognitive control, dependent on motivational intensity. This study has yet to be replicated, but is supported by

studies that have demonstrated a similar effect in relation to the influence of positive affect on attentional scope (e.g., Gable & Harmon-Jones, 2008b). Furthermore, despite findings from Wacker's (2017) study not being in line with the directional predications of the motivational intensity model (i.e., positive affect high vs. low in appetitive motivation resulting in increased vs. decreased stability respectively), these results do again indicate that the influence of positive affect on cognitive control processes may depend on motivational intensity. Therefore, it seems that recent work may be more in line with the motivational intensity model of positive affect, compared to the reward-as-motivation hypothesis.

2.3.3. Neurobiological Basis

Appetitive motivation is proposed to be related to activity in the mesocorticolimbic dopamine system, and this system is suggested to underlie a "behavioural facilitation system" (Depue & Collins, 1999). Dopamine neurons in the ventral tegmental area are argued to be activated by appetitive stimuli, resulting in an increase in dopamine projection to the nucleus accumbens and prefrontal cortex. Specifically, the subjective feelings and preparation of approach behaviour associated with appetitive motivation are suggested to occur due to an increase in dopamine activity in the nucleus accumbens (Smillie & Wacker, 2014). Importantly, it is argued that this activity is related only to "anticipatory" or "wanting" responses, whilst "consummatory" or "liking" responses are related to other neural substrates, outside of the mesocorticolimbic dopamine system (Depue & Collins, 1999).

2.3.3.1. Wanting vs. Liking

This suggestion was originally based animal studies, which have found only "wanting" responses are related to dopamine activity in the nucleus accumbens. For example, mice with lesions in this area (destroying 99% of dopamine projection) were found to display normal "liking" responses to sucrose (i.e., tongue protrusions) (Berridge & Robinson, 1998). However, mice with increased levels of dopamine projection in the nucleus accumbens have been found to have greater "wanting" (i.e., an increase in food and water intake), but not "liking" responses (Cagniard, Balsam, Brunner, & Zhuang, 2006; Peciña, Cagniard, Berridge, Aldridge, & Zhuang, 2003). In addition, dopamine agonists administered into the nucleus accumbens have been found to result in an increase in "wanting" (i.e., sucrose-associated lever pressing), but not "liking" responses (Wyvell & Berridge, 2000).

In contrast to “wanting”, “liking” responses are suggested to be related to neural substrates, other than the mesocorticolimbic dopamine pathway. This is supported by findings that opioid agonists injected into the shell of the nucleus accumbens result in an increase only in “liking” responses (Castro & Berridge, 2014). “Liking” responses have also been demonstrated to increase following the administration of cannabinoid agonists (Mahler, Smith, & Berridge, 2007), as well as a GABA benzodiazepine agonist (Richardson, Reynolds, Cooper, & Berridge, 2005). Furthermore, this latter study also demonstrated that administration of an opioid antagonist blocked this increase in “liking” responses. Therefore, this led Berridge (2009) to describe dopamine agonists as being strikingly unique, in terms of their failure to produce “liking” responses in these pharmacological animal experiments.

A similar distinction between “wanting” and “liking” responses has also been observed in humans. For example, Leyton et al. (2002) found that a dopamine agonist resulted in an increase in dopamine in the nucleus accumbens, which was more strongly correlated with subjective ratings of drug “wanting” compared to “liking”. However, dopamine antagonists have been found to reduce drug “wanting” when cocaine-dependent patients are exposed to cues (Berger et al., 1990; Smelson, Roy, & Roy, 1997). Furthermore, a dopamine agonist has been demonstrated to increase desire towards food, which was also found to be correlated with an increase in dopamine activity (Volkow et al., 2002). In addition, a dietary manipulation to deplete dopamine levels has been found to reduce ratings of only drug “wanting” when administering cocaine (Leyton, Casey, Delaney, Kolivakis, & Benkelfat, 2005).

However, administration of an opioid antagonist has been found to reduce drug “liking” ratings for heroin (Comer, Collins, & Fischman, 2001), whilst an opioid agonist has been found to increase drug “liking” ratings for morphine (Lamb et al., 1991). In this latter study, “liking” responses to low doses were also found not to predict self-administration the following day. Furthermore, following administration of a dopamine agonist, another study has found that there was an increase in drug “liking”, which was also found to be correlated with blood plasma levels of the drug (Morton et al., 2015). Interestingly, similar results have also been produced when participants view attractive faces, such that administration of an opioid agonist increases “liking” ratings of these, which were found to decrease when an opioid antagonist is administered (Chelnokova et al., 2014).

The studies described above mostly ask participants to self-report “wanting” or “liking” during exposure to drug cues or other appetitive stimuli, such as food. However, a limited number of studies have examined the affective feelings associated with these “wanting” (i.e., euphoria,

elation, excitement, and enthusiasm) and "liking" responses (i.e., pleasure, satisfaction, and contentment). For example, in relation to "wanting" responses, self-reported ratings of euphoria and excitement have been found to be positively correlated with the magnitude of dopamine that is released following the administration of dopamine agonists (Drevets et al., 2001; Laruelle et al., 1995). Furthermore, this has also been found to be the case when participants are anticipating the receipt of monetary gains, based on their performance in a cognitive task (Bjork et al., 2004).

In relation to "liking" responses, Eikemo et al. (2016) has demonstrated that the administration of an opioid agonist results in an increase in the self-reported pleasantness of sucrose solutions, whilst a decrease was reported following an opioid antagonist. This is supported by a review of studies in this area, which concluded that the pleasantness of food consumption in humans is consistently moderated by opioid antagonists and agonists (Yeomans & Gray, 2002). Furthermore, Schweiger, Stemmler, Burgdorf, and Wacker (2013) have demonstrated that an opioid antagonist reversed an increase in affective "liking" responses (assessed using adjectives, such as "comfortable" and "secure"), which was found to occur following a positive mood induction that used mental imagery and film clips. However, no effect was found on affective "wanting" responses (assessed using adjectives, such as "anticipation" and "driven").

Whilst it is suggested that dopamine projection to the nucleus accumbens facilitates the affective responses and behavioural tendencies associated with appetitive motivation, the prefrontal cortex has been argued to mediate the activation of related representations in working memory (Smillie & Wacker, 2014). The role of the prefrontal cortex in appetitive motivation is supported by numerous studies, which have demonstrated that activity in the prefrontal cortex increases during exposure to appetitive stimuli. This includes food, water, sex, addictive drugs, money, positive feedback, social interactions, as well as arbitrary conditioned appetitive stimuli, such as brief flashes of light (Knutson & Cooper, 2005). This increase in the activity in the prefrontal cortex has also been related specifically to dopamine activity. For example, activity of dopamine receptors in this area was found to be enhanced when cocaine users were exposed to drug-related cues (Miella et al., 2016).

2.3.3.2. Left Frontal Asymmetry

It has been suggested that appetitive motivation may be related to greater activity specifically in the left (compared to right) frontal areas of the cortex (Davidson, 1992), which is referred to as "left frontal asymmetry". This is based on evidence from studies that have used EEG

methodologies, to demonstrate greater left frontal asymmetry when infants viewed video clips of happy compared to sad faces (Davidson & Fox, 1982), which was also found to be the case when infants were approached by their mother compared to when separated (Fox & Davidson, 1987). Studies using samples of adults have also found some evidence that positive mood inductions (e.g., using affective film clips) may result in greater left frontal asymmetry (N. A. Jones & Fox, 1992; Reeves, Lang, Thorson, & Rothschild, 1989). However, other studies have found null (Collet & Duclaux, 1987; Meyers & Smith, 1986), or inconsistent results (Hagemann, Naumann, Becker, Maier, & Bartussek, 1998).

In a review of the literature, Harmon-Jones, Gable, and Peterson (2010) suggest that inconsistencies in the results of studies examining the influence of positive mood on left frontal asymmetry may be partially be due to a failure to take into account the motivational intensity of mood that is being induced. This is supported by a study conducted by Gable and Harmon-Jones (2008a), which examined the influence of positive affect that was high in appetitive motivation on left frontal asymmetry. Left frontal asymmetry was found to be greater when participants viewed images of desserts to induce positive affect that was high in appetitive motivation, compared to when participants viewed images of household objects to induce neutral affect. In addition, similar results were also found in a second study conducted by Harmon-Jones and Gable (2009), using a similar methodology to the previous study. Therefore, these studies suggest that it is positive affect high in appetitive motivation that results in an increase in left frontal asymmetry.

However, neither of the studies conducted by Harmon-Jones and Gable (i.e., Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009) examined the influence of positive affect that is low in appetitive motivation. Therefore, it may be the case this has the same effect on left frontal asymmetry as positive mood that is high in appetitive motivation. Based on this, a recent study conducted by Wacker (2016) examined left frontal asymmetry following separate mood inductions, using affective film clips and mental imagery, which were designed to induce positive affect that was associated with "wanting" (high in appetitive motivation) and "liking" responses (low in appetitive motivation). However, neither of these mood inductions were found to influence left frontal asymmetry. This may have been due to a failure to effectively induce positive mood states that were distinctively high and low in appetitive motivation, as expected changes in affect as a result of inductions were not observed.

Therefore, there are no studies to date that have (effectively) demonstrated the differential effect of positive affect that is high compared to low in appetitive motivation. Despite this,

there is some evidence from other studies demonstrating that left frontal asymmetry may be involved in appetitive motivation. For example, Costumero et al. (2013) examined self-reported individual differences in appetitive motivation, and found that these were positively correlated with the activation of only the left prefrontal cortex when participants viewed erotic images. Furthermore, Hughes, Yates, Morton, and Smillie (2015) examined left frontal asymmetry at rest in relation to performance on the Effort for Expenditure Reward Task, which requires participants to choose between low-effort and low-risk tasks and high-effort and high-risk tasks. It was found that those individuals with a greater left frontal asymmetry were more likely to expend effort when the chance of receiving the reward was lower.

Individual difference in left frontal asymmetry at rest have been demonstrated to be related to dopamine activity in the prefrontal cortex. For example, Wacker, Mueller, Pizzagalli, Hennig, and Stemmler (2013) examined left frontal asymmetry in relation to the Val158Met polymorphism of the COMT gene, which is associated with dopamine availability in the prefrontal cortex. Carriers of the Val allele (greater dopamine availability) were found to have greater left frontal asymmetry than carriers of the Met allele (lower dopamine availability). Furthermore, a positive correlation was found between left frontal asymmetry and self-reported individual differences in appetitive motivation, which was attenuated following the administration of a dopamine antagonist. In addition, Tomer et al. (2014) demonstrated that increased dopamine receptor binding in left prefrontal cortex predicted greater self-reported individual differences in appetitive motivation. This was also found to predict performance on a reinforcement learning task, such that this greater receptor binding was associated with a stronger preference for rewarding events.

Together, this research suggests that dopamine projection from the ventral tegmental area to the nucleus accumbens and prefrontal cortex may jointly coordinate appetitive motivation, in terms of enabling the anticipation of rewards and the activation of relevant mental representations (E. Miller & Cohen, 2001). Based on the dual-state model of the prefrontal cortex (Durstewitz & Seamans, 2008), it may be suggested that positive affect high in appetitive motivation results in greater dopamine projection to the prefrontal cortex, resulting in a state dominated by tonic D1 activity, facilitating greater stability (and reduced flexibility) in cognitive control. As positive affect low in appetitive motivation is related to the activity of neural substrates other than the mesocorticolimbic dopamine system (Depue & Collins 1999), this may be suggested to result in greater dopamine projection to the basal ganglia, resulting in

the suppression of a D2-mediated “NoGo” pathway (Frank & O’Reilly, 2006), and facilitating flexibility (and reduced stability) in cognitive control.

2.3.4. Interim Summary

Motivation can be described as the "drive" that an organism experiences (Hull, 1943) to reduce/induce innate emotional responses (Mowrer, 1960), occurring in response to certain biological stimuli that are aversive (e.g., injury) or appetitive (e.g., food, water, and sex) (Craig, 1917). Emotional responses that are associated with these stimuli eventually become associated with neutral predicting stimuli (i.e., "cues") through repeated pairing (Skinner 1938, 1958). Therefore, the organism will eventually engage in avoidance/approach behaviours (originally paired with aversive and appetitive stimuli) towards these cues. These associations are suggested to be maintained through reinforcement learning (Pavlov, 1927), such that behaviours leading to appetitive stimuli are more likely to be repeated, whilst those behaviours that do not are less likely to be repeated. The opposite process occurs for aversive stimuli, such that behaviours leading to these stimuli are less likely to be repeated, whilst behaviours that do not are more likely to be repeated.

There is a consensus that there are two primary motivational systems - one that is appetitive (mediating approach behaviours) and one that is aversive (mediating aversive behaviours) (A. Dickinson & Dearing, 1979; Konorski, 1969; Schneirla, 1959). An appetitive system has been termed as a "behavioural activation" or "behavioural facilitation" system, which is suggested to be involved in eliciting "anticipatory" and "wanting" responses (Gray & McNaughton, 2000; Depue & Collins, 1999). These responses are suggested to involve motivational feelings (i.e., desire, craving, and potency), as well as positive affect that is high in activation, such as feelings of excitement, euphoria, elation, and enthusiasm. This is argued to be distinct from the positive affect that is associated with “liking” responses, which occur at the later "consummation" stage of appetitive behaviour (Depue & Collins, 1999). This affect is described as being low in activation, and includes feelings such as gratification, satisfaction, enjoyment, and contentment.

The motivational intensity model (Gable & Harmon-Jones, 2010) suggests that positive affect high in appetitive motivation results in narrower/more stable cognition, whilst broader/more flexible cognition occurs for positive affect low in appetitive motivation. This is supported by studies demonstrating these effects on attentional scope (e.g., Gable & Harmon-Jones, 2008b) and Dreisbach and Goschke’s (2004) set-shifting paradigm (Liu & Wang, 2014). In contrast,

the reward-as-motivation hypothesis (Goschke & Bolte, 2014) proposes that appetitive motivation results in greater stability in cognitive control only when appetitive goals (i.e., rewards) are related to task performance, as this increase the motivation for an individual to engage in effortful control to optimise task performance (Aston-Jones & Cohen, 2005). Furthermore, this hypothesis also argues that positive affect that is unrelated to task performance results in greater flexibility in cognitive control. This is supported by studies demonstrating these differential effects for reward incentives and positive affect on the AX-CPT (e.g., Frober & Dreisbach, 2014).

Appetitive motivation is proposed to be related to increased activity in the mesocorticolimbic dopamine system (Depue & Collins, 1999). Specifically, dopamine projection to the nucleus accumbens is suggested to give rise to the affective feelings associated with appetitive motivation (Smillie & Wacker, 2014), whilst different neural substrates give rise to feeling associated with "consummatory" responses (e.g., Berridge & Robinson, 1998). Increased dopamine projection to the prefrontal cortex is proposed to be related to the activation of relevant mental representations (Smillie & Wacker, 2014), and there is evidence that this may occur specifically in frontal areas in the left hemisphere of the cortex (e.g., Gable, Harmon-Jones, & Peterson, 2010). Therefore, it may be suggested that positive affect that is high in appetitive motivation may result in greater stability in cognitive control due to an increase in D1 activity in the prefrontal cortex. However, positive affect that is low in appetitive motivation may result in greater flexibility in cognitive control due to an increase in D2 activity in the basal ganglia.

2.4. Summary and Aims

2.4.1. Positive Mood

Positive mood has been demonstrated to result in broader/more flexible cognition. For example, it has been found to result in a more global (as opposed to local) focus of attention (e.g., Gasper & Clore, 2002), as well as an increase in the breath of attentional scope (i.e., spatial attention) (e.g., Rowe et al., 2007). Positive mood has also been found to result in more diverse and unusual semantic associations (e.g., Isen, et al., 1985) and categorisations (e.g., Isen & Daubman, 1984), as well as more flexible reasoning and problem-solving (Isen, et al., 1987). It has also been demonstrated to enhance performance on creativity tasks that require divergent thinking – the process of producing a range of diverse solutions to a problem (compared to convergent thinking, which is the process of evaluating a single ultimate solution)

(e.g., Chermahini & Hommel, 2012). For example, performance has been found to be enhanced on the Alternate Uses Task (Guilford, 1967), which is a divergent thinking task that requires participants to produce as many alternate uses for a household object as possible (e.g., (R. S. Friedman et al., 2007).

The neuropsychological theory of positive affect (Ashby, et al. 1999) suggests that positive affect facilitates broader/more flexible cognition because it results in an increase in dopamine projection along two pathways in the brain: the nigrostriatal (projecting to the basal ganglia) and the mesocorticolimbic (projecting to the nucleus accumbens and the prefrontal cortex) pathways. Although genetic studies support the involvement of these pathways in divergent thinking, this association depends on numerous interactions between different genotypes (e.g., Runco et al., 2011). Other studies have used EBR as an index dopamine activity in the basal ganglia, to provide support the neuropsychological theory. Most notable was a study conducted by Chermahini and Hommel (2012), which demonstrated that EBR was related to divergent thinking in an inverted U-shape, and that a positive mood induction resulted in an increase in EBR. However, divergent thinking was only enhanced for those with a lower EBR prior to the induction, suggesting that the effect of positive mood is dependent on individual differences in baseline dopamine levels.

2.4.2. Cognitive Control

Positive affect has also been found to influence more basic and fundamental cognitive processes, such as the antagonistic balance between flexibility and stability in cognitive control (c.f., complex cognitive processes involved in creativity). This balance has been proposed to have complimentary context-dependent costs and benefits for goal-directed behaviour (Goschke, 2000). Specifically, flexibility in cognitive control may be beneficial for updating representations in working memory and shifting the focus of attention to a new goal, but costly in terms of increasing distractibility towards goal-irrelevant information. In contrast, stability may be beneficial for the active maintenance of current goals and shielding these representations from distraction, but costly in terms of increasing perseveration. Positive affect has been found to influence these processes, in terms of resulting in greater flexibility in cognitive control (at the cost of increased distractibility), using a set-shifting paradigm designed by Dreisbach and Goschke (2004), as well as attenuated stability (at the cost of increased perseveration), using the AX-CPT paradigm, which requires the active maintenance of task-relevant information (e.g., Dreisbach, 2006).

Neurobiological models of cognitive control processes have implicated an increase in dopamine projection to the basal ganglia as underlying flexibility in cognitive control. Specifically, Frank and O'Reilly (2006) propose that an increase in dopamine levels in the basal ganglia result in greater suppression of a D2-mediated "NoGo" pathway, which facilitates updating in working memory and a shift in the focus of attention. An inverted U-shaped relationship has been found between basal ganglia D2 activity and flexibility in cognitive control (Samanez-Larkin et al., 2014). Within this study, an increase in D2 activity was observed when a dopamine agonist was administered, and this enhanced set-shifting performance for those with lower baseline D2 activity. Therefore, an increase in nigrostriatal dopamine may also underlie findings of greater flexibility in cognitive control as a result of positive affect, which is in line with the neuropsychological theory (Ashby et al., 1999). However, this study also suggests that this effect, again, may depend on individual differences in dopamine activity at baseline.

It has been suggested that EBR may specifically reflect D2 dopamine activity in the basal ganglia. However, this may depend on whether EBR is being assessed at rest or following a manipulation to influence dopamine activity. For example, Groman et al. (2014) demonstrated that only D2 receptor neuron density predicted EBR at baseline, but EBR was found to be increased following both D1 and D2 agonists. The finding that pharmacological manipulations targeting D1 and D2 receptors both affect EBR in the same direction is supported by numerous animal studies (Elsworth et al., 1991; Lawrence & Redmond, 1991). EBR assessed at baseline has been demonstrated to affect the balance between flexibility and stability in cognitive control, such that those individuals with a greater EBR display the same pattern of results on Dreisbach and Goschke's (2004) set-shifting paradigm as is demonstrated for positive affect – enhanced flexible switching (at the cost of increased distractibility) (Dreisbach et al., 2005). This supports the suggestion that positive affect results in greater flexibility due to an increase in D2 activity in the basal ganglia.

The neuropsychological theory of positive affect (Ashby et al., 1999) also suggests that an increase in mesocorticolimbic dopamine activity facilitates previously observed effects for positive mood on cognition. However, Durstewitz and Seamans (2008) argue that an increase in dopamine activity in the prefrontal cortex stimulates D1 receptor activity, facilitating the active maintenance of contextual representations, and greater stability in cognitive control. In line with this suggestion, a review of the literature concluded that D1 activity in the prefrontal cortex is related to performance on tasks requiring the active maintenance (i.e., greater

stability) in an inverted U-shape (Floresco, 2013). Again, this suggests that any effects of manipulations targeting dopamine activity may depend on individual differences at baseline. Despite this, these findings suggest that attenuated stability (and greater flexibility) may occur as a result of positive affect due to a decrease in (D1 activity in the prefrontal cortex), as opposed to the increase that is suggested to underlie this effect in the neuropsychological theory of positive affect (Ashby et al., 1999).

2.4.3. Appetitive Motivation

However, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that it is only positive affect low in appetitive motivation that promotes broader cognition, as this facilitates exploratory behaviour and the building of personal resources in a safe environment (Fredrickson, 1998). In contrast, positive affect high in appetitive motivation is suggested to promote narrower cognition, to facilitate the successful pursuit of rewards. This model is supported by studies demonstrating that positive mood that is high compared to low in appetitive motivation results in a narrower compared to broader attentional scope respectively (e.g., Gable & Harmon-Jones, 2008b). However, the moderating role of appetitive motivation has not yet been examined in relation to the influence of positive mood on other processes outlined above, such as divergent thinking and creativity. This is despite the fact that mood inductions used in previous studies have varied in design and motivational intensity is often unclear, such as asking participants to imagine a “pleasant” or “happy” events, compared to presenting participants with gifts.

Despite this, Liu and Wang (2014) have found that the influence of positive affect on Dreisbach and Goschke’s (2004) set-shifting paradigm was also moderated by motivational intensity. Specifically, positive affect low in appetitive motivation was found to enhance flexibility (and increase distractibility), whilst flexibility was attenuated (and distractibility was decreased) for positive affect high in appetitive motivation. This suggests that the motivational intensity model can be expanded to the balance between flexibility and stability in cognitive control. However, this has only been demonstrated in one study to date (c.f., moderation of attentional scope has been demonstrated in several studies). Also, this study only induced positive affect using transient emotional responses, and it is unclear whether findings can be applied to more enduring mood states (i.e., used in studies examining attentional scope and creativity). Although the effect of positive mood states varying in motivational intensity on the AX-CPT

has been examined in one study (i.e., Wacker, 2017), but this study did not effectively induce mood states and produced null results.

Other studies have examined the effect of performance-dependent rewards on cognitive control, finding greater stability on the AX-CPT (e.g., Locke & Braver, 2008), and reduced flexibility on the attentional set-shifting paradigm (Muller, Dreisbach, Goschke, et al., 2007) The reward-as-motivation hypothesis (Goschke & Bolte, 2014) proposes that performance-based rewards (or appetitive goals) increase motivation to engage in effortful control, functioning to optimise reward-pursuit (Aston-Jones & Cohen, 2005). However, positive affect that is unrelated to task performance results in greater flexibility, allowing an exploratory mode of behaviour, which facilitates switching to new goals or opportunities (Carver, 2003). In contrast to the motivational intensity model (Gable & Harmon-Jones, 2010), the reward-as-motivation hypothesis argues that appetitive motivation must be related to task performance to facilitate stability in cognitive control. However, this suggestion is inconsistent with Liu and Wang's (2014) finding of greater stability as a result of positive affect high in appetitive motivation (i.e., which was unrelated to task performance).

Positive affect that is high in appetitive motivation is suggested to be experienced in "pre-goal" situations, and is associated with "anticipatory" or "wanting" responses. It is characterised by motivational feelings of desire, as well as positive affective feelings that are high in activation, such as excitement, euphoria, elation, and enthusiasm (Depue & Collins, 1999). In contrast, positive affect that is low in appetitive motivation is suggested to be experienced in "post-goal" situations, and is associated with "consummatory" or "liking" responses. It is characterised by positive affect that is low in activation, such as gratification, satisfaction, and contentment. Positive affect that is high in appetitive motivation is suggested to result in an increase in activity in the mesocorticolimbic dopamine system, whilst positive affect that is low in appetitive motivation is proposed to be related to other neural substrates, such as the opioid system in the shell of the nucleus accumbens (Berridge & Robinson, 1998). Therefore, in this way, these types of positive affect are distinct at a psychological, behavioural, and neurobiological level.

There is a wealthy of evidence from animal studies, which demonstrate that only "wanting" responses are associated with mesocorticolimbic dopamine activity, whilst "liking" responses are associated with opioid activity (Berridge, 2009). Human studies have also demonstrated that only "wanting" responses are increased following the administration of dopamine agonists (e.g., Leyton et al., 2002), as well as only "wanting" responses being reduced following

dopamine antagonists (Berger et al., 1990). However, "liking" responses are found to be increased following the administration of opioid agonists (Chelnokova et al., 2014), but decreased following opioid antagonists (Comer et al., 2001). Fewer studies have examined the effects of dopamine agonists and antagonists on responses that are more closely related to positive affect. However, these studies have provided some evidence that dopamine agonists only increase self-reported "excitement" and "euphoria" (Drevets et al., 2001), whilst opioid agonists increase "pleasantness" (Eikemo et al., 2016).

Appetitive motivation has also been demonstrated to result in greater activity in the left compared to right frontal areas of the cortex, which is referred to as left frontal asymmetry (Davidson, 1999). Left frontal asymmetry has been demonstrated to increase as a result of positive affect high in appetitive motivation. However, this has only been demonstrated following the brief presentation of appetitive images (e.g., Gable & Harmon-Jones, 2008a), which are likely only to induce transient emotional responses. Again, it is unclear whether these findings can be expanded to more enduring mood states (i.e., those that have been demonstrated to influence attentional scope and creativity). There is also no research to date that has examined the differential effects of positive affect that is high and low in appetitive motivation on left frontal asymmetry. Furthermore, although dopamine activity has been linked to left frontal asymmetry at rest (e.g., Tomer et al., 2014), there is no current evidence to suggest that this underlies the effect of positive affect on left frontal asymmetry.

Together, this literature suggests that motivational intensity may moderate the influence of positive affect on cognition. Specifically, positive affect low in appetitive motivation may result in broader and more flexible cognition, whilst narrower and more stable cognition may occur as a result of positive affect that is high in appetitive motivation. This literature also suggests that different neurobiological mechanisms may be involved in these effects, such that positive affect low in appetitive motivation may result in broader and more flexible cognition due to an increase in D2 activity in the basal ganglia. However, positive affect that is high in appetitive motivation may result in narrower and more stable cognition due to an increase in D1 activity in the prefrontal cortex. There is also evidence that cognitive performance is optimal at medium levels of dopamine, such that the effects of positive mood may depend on baseline (i.e., pre-existing levels). Furthermore, increases in prefrontal activity that are proposed to occur for positive mood high in appetitive motivation may be lateralised to the left cortical hemisphere.

2.4.3.1. Current Research Aims

The first aim of the current research is to examine the moderating role of appetitive motivation in relation to the influence of positive mood on cognition. The differential effects of positive mood states that are high and low in appetitive motivation has not been previously examined in relation to creativity (i.e., on divergent and convergent thinking tasks). Therefore, this will be examined in Studies 1 and 2. Limited research has examined the moderating role of appetitive motivation in relation to the influence of positive affect on the processes involved in the balance between flexibility and stability in cognitive control, and studies in this area that have been conducted have only examined the effect of transient emotional responses (e.g., Liu & Wang, 2014). Therefore, Studies 3, 4, and 5 will explore the influence of more enduring positive mood states high and low in appetitive motivation on the balance between flexibility and stability in cognitive control. The effects on the costs and benefits of flexibility will be examined using Dreisbach and Goschke's (2004) set-shifting paradigm (Study 3 and 4), whilst the costs and benefits of stability will be examined using the AX-CPT (Study 5).

The second aim is to examine possible neurobiological mechanisms that may underlie the influence of positive mood that is high and low in appetitive motivation on cognition, using indirect physiological measures of this activity. As the differential effects of these positive mood states have not previously been examined in relation to EBR, this will be examined in Studies 1, 2, 4, and 5. EBR will also be examined in relation to the more complex cognitive processes (i.e., creativity) in Study 1 and 2, whilst Studies 4 and 5 will examine EBR in relation to more fundamental and basic processes – specifically in relation to the balance between flexibility and stability in cognitive control (i.e., using Dreisbach & Goschke's set-shifting paradigm in Study 4 and the AX-CPT in Study 5). Finally, Study 6 will examine the effect of positive mood states that are high and low in appetitive motivation on left frontal asymmetry, using an EEG methodology, as well as the relationship between EBR and left frontal asymmetry, as this has not been examined in previous research.

Therefore, the current research addresses the following research questions:

- Does appetitive motivation moderate the influence of positive mood on cognition? Is this the case for complex cognitive processes, such as creativity (Studies 1 and 2)? Can previous findings demonstrating effects of brief emotional responses on more fundamental basic cognitive processes (i.e., balance between flexibility and stability in cognitive control) be extended to more enduring mood states (Studies 3, 4, and 5)?

- How does positive mood that is high and low in appetitive motivation moderate EBR? Does only positive mood that is low in appetitive motivation result in an increase in EBR (Studies 1, 2, 4, and 5)?
- How is EBR at rest related to cognition? Can findings of an inverted U-shaped relationship between EBR and divergent thinking be replicated (Studies 1 and 2)? How is EBR related to convergent thinking (Study 1)? How does EBR relate to the balance between flexibility and stability in cognitive control (Studies 4 and 5)? Can previous findings that EBR at rest moderates set-shifting performance be replicated (Study 4)?
- Do individual differences in baseline EBR (i.e., at rest) moderate the influence of positive mood on cognition? Can the moderating effect for divergent thinking that has been previously observed be replicated, and does this depend on the motivational intensity of positive mood (Studies 1 and 2)? Does a moderating effect occur for the influence of positive mood on cognitive control processes? Specifically, does EBR moderate the influence of positive mood on set-shifting performance, and does this depend on motivational intensity (Study 4)?
- Does appetitive motivation moderate the influence of positive mood on left frontal asymmetry? Can previous findings of an increase in left frontal asymmetry for positive mood that is high in appetitive motivation be replicated? Can it be demonstrated that this increase does not occur for positive mood that is low in appetitive motivation? (Study 6).
- How does EBR relate to left frontal asymmetry? (Study 6).

3. Study 1 – Positive mood, creativity and spontaneous eye blink rate: The influence of appetitive motivation

3.1. Abstract

Study 1 aimed to examine whether the effect of positive mood on creativity was dependent on appetitive motivation. This was based on the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect low in appetitive motivation may be beneficial for broad and flexible cognition, whilst narrower and more stable cognition may benefit from positive affect high in appetitive motivation. This aim was examined in relation to two types of creativity: divergent thinking (requires broader/more flexible cognition), and convergent thinking (requires narrower/more stable cognition). In addition, based on the suggestion that the influence of positive affect on cognition may be related to dopamine activity (Ashby et al., 1999), a further aim was to examine the effect of these positive mood states on EBR, as well as the relationships between EBR and creativity (i.e., divergent and convergent thinking).

Sixty-nine participants completed a laboratory-based experimental study and were randomly assigned to a high or low appetitive condition. A positive mood induction was completed, which involved listening to music and imagining scenarios (Smillie, Cooper, Wilt, & Revelle, 2012). At pre-and post-induction timepoints, positive affect was measured using the UMACL (UWIST Mood Adjective Checklist; Matthews, Jones, & Chamberlain, 1990) and EBR was assessed by video recording. This was followed by completion of the Alternate Uses Task (Guilford, 1967) to assess divergent thinking and a set of remote associate problems based on the Remote Associates Test (Mednick, 1962) to assess convergent thinking.

ANOVAs demonstrated that there were no effects of mood inductions on positive affect, suggesting these were not effective in inducing positive mood states high and low in appetitive motivation. This may explain null results for the effect of mood inductions on divergent and convergent thinking, as well as EBR. However, non-significant negative linear trends were observed between baseline EBR and divergent, as well as convergent, thinking using regression analysis. Furthermore, a non-significant trend was found, suggesting that increases in EBR following mood inductions were associated with decreases in divergent/convergent thinking. Therefore, this suggests a non-specific negative relationship between dopamine activity and creativity.

3.2. Introduction

3.2.1. Positive Mood and Divergent Thinking

Empirical studies demonstrate that positive mood results in a broader attentional scope (e.g., Rowe et al., 2007), access to more diverse associations (e.g., Isen et al., 1985), and more flexible categorisation and reasoning (e.g., Isen & Daubman, 1984). There is also evidence that positive mood may enhance creativity, although this is argued to be dependent on the type of task used to assess this (Davis, 2009). One component of creativity is ideation (the production of unique or novel ideas), which is suggested to require *divergent thinking* – the process of generating multitude of solutions to a problem (Guilford, 1967). This is proposed to require an individual to shift perspective or their approach towards solving a problem, which results in a range of diverse solutions, and increases the likelihood of a unique or novel idea being produced. It has been suggested that positive mood may enhance performance on creativity tasks that assess divergent thinking, as broad and flexible cognition may be beneficial for this process (Hommel, 2012).

Divergent thinking can be assessed using the Alternate Uses Task (Christensen, Guilford, Merrifield, & Wilson, 1960), which requires participants to provide as many different uses for a household object as possible. Although there is some criticism of utilising psychometric tasks to assess the complex concept of creativity, divergent thinking tasks have been demonstrated to have reasonable reliability and validity (Runco & Acar, 2012). Therefore, these tasks have been used extensively in empirical studies of creativity, including in the study of positive mood (Gilhooly, Fioratou, Anthony, & Wynn, 2007). These studies have demonstrated that self-reported ratings of positive mood are positively associated with performance on the Alternate Uses Task (Vosburg, 1998), and that performance on this task is enhanced following positive mood inductions (R. S. Friedman et al., 2007; Tan & Qu, 2014; Vosburg, 1998). This supports the suggestion that positive mood results in enhanced performance of creativity tasks that require broad and flexible cognition, such as those assessing divergent thinking.

3.2.2. EBR and Divergent Thinking

Findings that positive mood enhances divergent thinking task performance, as well as other aspects of cognition requiring broad and flexible cognition, led to the development of the neuropsychological theory of positive affect (Ashby et al., 1999). This suggests that positive mood results in broader and more flexible cognition because it causes an increase in dopamine

activity. This is suggested to occur in two dopamine sub-systems: i) the nigrostriatal pathway, which projects from the substantia nigra to the dorsal striatum in the basal ganglia, and ii) the mesocorticolimbic pathway, which projects from the ventral tegmental area to the prefrontal cortex and nucleus accumbens. It is argued that increases in dopamine along these pathways improves performance on divergent thinking tasks by allowing dominant sets to be overcome, and facilitating the activation of non-dominant sets when searching for multiple solutions.

A relationship between dopamine activity and flexible cognition was supported by a series of experimental studies conducted by Chermahini and Hommel (2010). Within these studies, divergent thinking was assessed using the Alternate Uses Task, and performance was examined in relation to EBR. This was suggested to reflect dopamine activity specifically in the nigrostriatal pathway, based on studies demonstrating increases/decreases for clinical samples of patients with disorders associated with aberrant dopamine activity (e.g., L. Chen et al., 2010; Fitzpatrick et al., 2012). Chermahini and Hommel (2010) found that the relationship between EBR and divergent thinking best fitted an inverted U-shape, suggesting that divergent thinking was most enhanced at medium levels of nigrostriatal dopamine. Therefore, it was theorised that positive mood may result in an increase in dopamine projection along the nigrostriatal pathway. However, the non-linear relationship suggests increases in divergent thinking task performance as a result of positive mood depend on baseline levels of dopamine activity.

The inverted U-shaped relationship between EBR and divergent thinking task performance has been replicated in a second study conducted by Chermahini and Hommel (2012), which was suggested to provide evidence of a reliable non-linear relationship between creativity and nigrostriatal dopamine activity. This study also examined the influence of positive mood on the relationship between EBR and divergent thinking, by examining EBR and performance on the Alternate Uses Task both before (i.e., at baseline) and after a positive or negative mood induction. Positive (but not negative) mood was found to result in an increase in EBR and performance on the divergent thinking task. Furthermore, increases in positive (but not negative) affect and EBR were both found to be associated with increases in divergent thinking performance. Therefore, this provides evidence to support the suggestion that it is increases in nigrostriatal dopamine activity that may underlie findings that positive mood results in broader and more flexible cognition, in relation to divergent thinking.

Within this study, Chermahini and Hommel (2012) also examined whether baseline EBR would moderate the influence of positive mood on divergent thinking task performance, testing the inverted U-shape theory. To do this, performance was examined separately for participants

with higher and lower EBR prior to the mood induction. It was found that the positive mood induction resulted in an increase in divergent thinking performance only for participants with a lower EBR prior to the mood induction. Although yet to be replicated, this suggests that increases in divergent thinking performance due to increases in positive mood may be mediated by increases in dopaminergic activity in the nigrostriatal pathway. However, it also suggests that the effect of positive mood on divergent thinking is moderated by individual differences in baseline dopamine activity, such that only those with lower levels of baseline nigrostriatal activity display increases in divergent thinking performance as a result of positive mood.

3.2.3. Positive Mood and Convergent Thinking

However, creativity not only involves ideation, but also evaluation – the determination of which ideas are the most useful or appropriate (Runco & Chand, 1995). Evaluation is proposed to require *convergent thinking*, which involves logically working through a number of ideas, in order to derive the ultimate solution (Guilford, 1967). This can be assessed using the Remote Associates Test (Mednick, 1962), in which participants are presented with three words (e.g., cream, skate, water), and are required to find the word that semantically links all three together (e.g. ice). It has been suggested that, whilst broad and flexible cognition may be beneficial for divergent thinking tasks, narrower and more stable cognition may be advantageous for performance on convergent thinking tasks (Hommel, 2012). This is because, rather than producing many diverse ideas, as is required for divergent thinking (i.e., providing a number of possible uses for a household object when completing the Alternate Uses Task), convergent thinking requires an individual to systematically deduce and isolate the correct solution to a problem (i.e., the single word that correctly links together the three words presented in the Remote Associates Test).

The Remote Associates Test has good psychometric properties, and convergent validity has been demonstrated in relation to other tasks that may require convergent thinking. For example, Taft and Rossiter (1966) demonstrated that there were moderate positive correlations between performance on the Remote Associates Test and other measures that require convergent thinking, including school achievement and measures of intelligence, such as Raven's Advanced Progressive Matrices (Raven, Court, & Raven, 1977; Raven, Raven, & Court, 1998). C. S. Lee, Huggins, and Therriault (2014) also demonstrated this moderate positive correlation with Raven's Advanced Progressive Matrices, as well as a similar correlation for the Remote Associates Test and another measure of intelligence, the Wechsler's Adult Intelligence Scale-

Revised (Wechsler, 1958). Furthermore, this study also demonstrated that performance on the Remote Associates Test was moderately positively correlated with working memory tasks requiring deductive and systematic thinking, such as the Backward Digit Span task (Wilde, Strauss, & Tulsky, 2004), which requires participant to recall a series of digits in reverse order.

However, several studies have found that positive mood inductions in fact result in enhanced performance on the Remote Associates Test (Estrada et al., 1994; Isen et al., 1987; Rowe et al., 2007). This seems at odds with findings that positive mood generally results in broader and more flexible cognition, including enhanced performance on divergent thinking tasks. One possible explanation could be that the Remote Associates Test requires an element of divergent thinking to generate a number of possible solutions to the problem, prior to examining the acceptability of these (Smith, Huber, & Vul, 2012). However, performance on the Remote Associates Test has consistently been demonstrated to have only a weak positive correlation with measures of divergent thinking, such as the Alternate Uses Task (Chermahini & Hommel, 2012; C. S. Lee et al., 2014; Taft & Rossiter, 1966). Furthermore, using structural equation modelling, C. S. Lee and Therriault (2013) demonstrated convergent and divergent thinking were distinct latent variables when performance was examined across creativity tasks. Therefore, the suggestion that the Remote Associates Test requires an element of divergent thinking appears to offer, at best, only a partial explanation of why positive mood may result in enhanced performance on this task.

3.2.4. Appetitive Motivation and Creativity

Another possible explanation may be due to the types of mood inductions that are utilised in these studies. The motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognition may be moderated by appetitive motivation. Positive affect that is high in appetitive motivation (e.g., excitement) can be described as having a similar affective valence to positive affect that is low in appetitive motivation (e.g., contentment). However, positive affect that is high in appetitive motivation is characterised by a greater level of activation (Depue & Collins, 1999). The motivational intensity model suggests that broader and more flexible cognition may result from positive affect that is low in appetitive motivation, whilst positive affect that is high in appetitive motivation may result in narrower and more stable cognition. However, the motivational intensity (or the level of appetitive motivation) elicited by mood inductions is not considered in previous studies examining the influence of positive mood on creativity.

Studies demonstrating that positive mood results in enhanced performance on divergent thinking tasks often use mood inductions that involve mental imagery of 'happy' or 'pleasant' autobiographical memories (R. S. Friedman et al., 2007; Tan & Qu, 2014; Vosburg, 1998). This may be suggested to induce a positive mood state that is low in appetitive motivation, which would be in line with the proposition that this promotes broader and more flexible cognition (i.e., is beneficial for divergent thinking tasks). However, studies that have shown that positive mood results in enhanced performance on convergent thinking tasks have often used mood inductions that involved presenting participants with gifts, such as sweets and chocolates (e.g., Isen et al., 1987). Given the appetitive nature of these stimuli, this could be suggested to have induced positive mood that is high in appetitive motivation. Therefore, this would be in line with the suggestion that this type of positive mood state promotes narrower and more stable cognition (i.e., is beneficial for performance on convergent thinking tasks).

Depue and Collins (1999) suggest that positive affect high in appetitive motivation is related to activity of the mesocorticolimbic dopamine system, resulting in an increase in dopamine activity in the prefrontal cortex. However, positive affect low in appetitive motivation is related to other separate neural substrates. This suggestion is in line with the motivational intensity model of positive affect (Gable & Harmon-Jones, 2010), when neurobiological models of cognitive control are considered. To elaborate, these models suggest that processes associated with more stable cognition are related to an increase in dopamine activity in the prefrontal cortex (Durstewitz & Seamans, 2008), whilst the processes associated with more flexible cognition are related to an increase in dopamine activity in the basal ganglia (Frank & O'Reilly, 2006). However, it is important to note that the balance between processes associated with more stable and flexible cognition are proposed to be antagonistic (Goschke, 2000), as is the relationship between dopamine activity in the prefrontal cortex and the basal ganglia, which is suggested to underlie these processes (Cools & D'Esposito, 2011).

Based on this, it may be suggested that positive mood high in appetitive motivation facilitates narrower/more stable cognition due to an increase in dopamine activity in the prefrontal cortex (and possible reciprocal decrease in the basal ganglia). However, positive mood low in appetitive motivation may facilitate broader/more flexible cognition due to an increase in dopamine activity in the basal ganglia (and possible reciprocal decrease in the prefrontal cortex). Chermahini and Hommel (2010) explored the neurobiological mechanisms underlying convergent thinking by examining the relationship between EBR and performance on the Remote Associates Test. No significant relationship found, supporting the suggestion that

activity outside of the nigrostriatal pathway (i.e., possibly the mesocorticolimbic pathway) is involved in mediating narrower/more stable cognition, as is required for convergent thinking. However, a trend towards a negative linear relationship between EBR and performance on the Remote Associates Test was observed, which eludes to a reciprocal relationship between nigrostriatal dopamine activity and convergent thinking.

3.2.5. Present Study

Positive mood has been found to enhance performance on creativity tasks that require divergent (e.g., R. Friedman et al., 2007) and convergent thinking (e.g., Isen et al., 1987). However, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognitive depends on motivational intensity. This is such that positive affect high in appetitive motivation is suggested to result in narrower and more stable cognition, whilst broader and more flexible cognition is suggested to occur as a result of positive affect low in appetitive motivation. In line with this model, appetitive motivation has been found to moderate the influence of positive affect on attentional scope (e.g., Gable & Harmon-Jones, 2008b), as well as the balance between flexibility and stability in cognitive control (e.g., Liu & Wang, 2014). Despite this, the moderating effect of appetitive motivation has not been previously examined in relation to the influence of positive mood on creativity. Therefore, the first aim of the present study is to examine whether appetitive motivation moderates the influence of positive mood on convergent and divergent thinking processes in creativity.

To address this aim, performance on divergent and convergent thinking tasks will be examined before and after participants undergo a positive mood induction that is either high or low in appetitive motivation. Based on the motivational intensity model (Gable & Harmon-Jones, 2010), it is hypothesised that positive mood low in appetitive motivation will only enhance divergent thinking, whilst convergent thinking will be enhanced only for positive mood high in appetitive motivation. This assumes that broader/more flexible cognition is beneficial for divergent thinking, whilst narrower/more stable cognition is beneficial for convergent thinking (Hommel, 2012). Although previous research suggests that positive mood may enhance both processes, this may be due to the use of appetitive stimuli during mood inductions in studies examining convergent thinking (e.g., Isen et al., 1987). It is also important to note, that trends towards attenuated divergent and convergent thinking may also be expected for high and low appetitive mood inductions, due the antagonistic relationship that is suggested to exist between these processes (Goschke, 2000).

The second aim of the present study was to explore the neurobiological mechanisms that may underlie the influence of positive mood on creativity, using indirect measures of dopamine activity. EBR will be assessed before and after the positive mood inductions that are high and low in appetitive motivation. Chermahini and Hommel (2012) found that EBR increased after a positive mood induction (assumed to be low in appetitive motivation), and this was argued to reflect an increase in nigrostriatal dopamine activity. However, although EBR may primarily reflect dopamine activity in the basal ganglia when assessed at baseline (Jongkees & Colzato, 2016), pharmacological manipulations targeting specific receptor subtypes found predominantly in the basal ganglia or prefrontal cortex have both been demonstrated to increase EBR (e.g., Elsworth et al., 1991). As Depue and Collins (1999) suggest that positive mood high in appetitive motivation is related to dopamine activity in the mesocorticolimbic system, it could be the case that this induction may also result in an increase in EBR. Therefore, an exploratory approach will be taken to examine the influence of positive mood states on EBR.

The present study will also explore the relationship between baseline EBR and creativity. Chermahini and Hommel (2010) demonstrated that baseline EBR was related to divergent thinking in an inverted U-shape, whilst a trend towards a negative linear relationship was observed for EBR and convergent thinking performance. This is in line with models of cognitive control suggesting that flexibility is related to greater dopamine in the basal ganglia (Frank & O'Reilly, 2006). As an antagonistic relationship is suggested to exist with stability in cognitive control (Goschke, 2000), this may explain the negative trend between EBR and convergent thinking. Based on the suggestion that EBR at baseline primarily reflects dopamine activity associated with the basal ganglia (Jongkees & Colzato, 2016), it is expected that the findings of Chermahini and Hommel (2010) will be replicated in the present study. Therefore, it is hypothesised that there will be an inverted U-shaped relationship between EBR and divergent thinking, whilst there will be no relationship (or a possible negative trend) between EBR and convergent thinking.

Chermahini and Hommel (2012) suggested that an increase in nigrostriatal dopamine may result in an increase in flexibility as a result of positive mood. This was supported by their findings that there was a positive relationship between increases in divergent thinking and increases in positive affect and EBR. Therefore, these relationships will also be examined in the present study, including in relation to changes in convergent thinking. Based on descriptions of positive affect that is high and low in appetitive motivation (Depue & Collins, 1999), it is hypothesised that only increases in deactivated positive affect will be associated

with increases in divergent thinking, whilst only increases in activated positive affect will be associated with convergent thinking. However, again, due to the antagonistic relationship described between these processes (Goschke, 2000), it may also be expected that trends towards negative relationships could also be observed between changes in deactivated positive affect and convergent thinking performance, as well as between changes in activated positive affect and divergent thinking performance.

Due to findings that EBR may increase following pharmacological manipulations that increase dopamine activity in both the nigrostriatal and mesocorticolimbic pathways (e.g., Elsworth et al., 1991), an exploratory approach will be taken to examine the relationships between change in EBR and creativity. However, Chermahini and Hommel (2012) found that baseline EBR moderated the effect of positive mood on divergent thinking, such that this was enhanced only for those individuals with a lower baseline EBR. The present study hypothesises that there will be an inverted U-shaped relationship between EBR and divergent thinking at the pre-induction timepoint, whilst convergent thinking will be (statistically) unrelated to EBR. Furthermore, divergent thinking performance is hypothesised to be enhanced only by positive mood that is low in appetitive motivation. Therefore, it is also hypothesised that pre-induction EBR will moderate the influence of positive mood low in appetitive motivation on creativity, resulting in enhanced divergent thinking performance only for those individuals with a lower baseline EBR.

3.2.6. Aims and Hypotheses

1. To examine whether appetitive motivation moderates the influence of positive mood on convergent and divergent thinking processes in creativity.

   i) It is hypothesised that positive mood low in appetitive motivation will only enhance divergent thinking, whilst convergent thinking will be enhanced only for positive mood high in appetitive motivation.

2. To explore the neurobiological mechanisms that may underlie the influence of positive mood on creativity, using indirect physiological measures of dopamine activity (i.e., EBR).

   i) An exploratory approach will be taken to examine the influence of positive mood states on EBR.

ii) It is hypothesised that there will be an inverted U-shaped relationship between EBR and divergent thinking, whilst there will be no relationship (or a possible negative trend) between EBR and convergent thinking.

iii) It is hypothesised that only increases in deactivated positive affect will be associated with increases in divergent thinking, whilst only increases in activated positive affect will be associated with convergent thinking

iv) An exploratory approach will be taken to examine the relationships between change in EBR and creativity.

v) It is hypothesised that pre-induction EBR will moderate the influence of positive mood low in appetitive motivation on creativity, resulting in enhanced divergent thinking performance only for those individuals with a lower pre-induction EBR.

3.3. Method

3.3.1. Participants

Sixty-nine participants were recruited, which is in line with previous studies (cf. Chermahini & Hommel, 2012). There were 51 (73.90%) female and 18 (26.10%) male participants, with an age range of 18-58 years (M = 22.51 years, SD = 6.88), who were undergraduate psychology students from a London university. Of these, 60 were recruited using the Department of Psychology's Research Participation Scheme, whilst nine were recruited after responding to an advertisement placed in seminars, and all received course credit for participation. Participants were randomly assigned to one of the two positive mood induction conditions: high appetitive motivation (n = 35) and low appetitive motivation (n = 34). The study was approved by the University Research Ethics Committee, and all participants provided informed consent at the start of the study, and were fully debriefed at the end of the study.

3.3.2. Measures

3.3.2.1. Mood Induction

Participants completed a mood induction to induce either positive mood that was high in appetitive motivation or positive mood that was low in appetitive motivation. Mental imagery based on vignettes and music was used, as research suggests that combined modalities are the most effective for mood inductions (e.g., Mayer, Allen, & Beauregard, 1995). The mood

induction stimuli (and procedure) were adapted from other studies that had used these stimuli to differentially induce the affective components associated with positive mood that is high and low in appetitive motivation (Larsen & Ketelaar, 1989; Mayer et al., 1995; Smillie et al., 2012). Participants were presented with two vignettes that required them to imagine a scenario occurring in their lives. The scenarios were presented in sequence and each required the participant to engage in mental imagery for approximately 3min. The music began when the first scenario was presented, and continued to play throughout the mood induction period, which was 6min long in total. Prior to each scenario participants were given the following written instructions:

"You will be presented with two scenarios whilst you listen to music. You should read each scenario and imagine yourself experiencing the events as vividly as you can. Picture the event happening to you. Try to imagine all the details of the situation. You should close your eyes and picture in your 'mind's eye' the surroundings as clearly as possible. See the people or objects; hear the sounds; experience the event happening to you. Think the thoughts and feel the same feelings that you would actually think in this situation. Let yourself react as if you were actually there. Later you will be asked to recall parts of the scenario so the more you are able to 'get into the feeling' of each scene, the more you are likely to recall".

The vignettes selected for the positive mood condition high in appetitive motivation involved themes of reward-pursuit and desire: "*You buy a lottery ticket and you win £200.00 instantly*" and "*It's your birthday and your friends throw you a terrific surprise party*", whereas the vignettes for the positive mood condition that was low in appetitive motivation involved themes of pleasure and contentment. These were: "*You are lying in the warmth of the sun on a tropical beach, with the sound of gentle waves in the background*" and "*You feel totally relaxed as you have a nice warm bath at the end of long day*". Participants in the appetitive condition listened to "*Waltz of the Flowers*" from the "*Nutcracker Suite*" by Tchaikovsky when engaging in mental imagery, whilst participants in the pleasant condition were listening to "*Venus*" from "*The Planets*" by Holst.

3.3.2.2. Positive Affect

The UMACL (UWIST Mood Adjective Checklist; Matthews, Jones, & Chamberlain, 1990) was used to measure self-reported positive affect. It is a 29-item measure, for which participants respond to adjectives on a 4-point Likert-type scale, ranging from 1 (definitely not) to 4 (definitely), based on their present mood. The UMACL separates the basic dimensions of

affect suggested in structural models, in terms of activation and valence (Russell, 1980; Thayer, 1989; Watson & Tellegen, 1985). These dimensions are reflected in three scales: Tense Arousal, which reflects negative activation, and is measured using adjectives such as 'tense'; Energetic Arousal, which reflects positive activation, and is measured using adjectives such as 'alert'; and Hedonic Tone, which reflects the valence dimension of affect, and is measured using adjectives such as 'happy' and 'sad'. Summing scores for items on each scale gives a total score for that scale, such that higher scores indicate greater experience of the respective dimension of affect within an individual's mood.

The UMACL has been demonstrated to have good reliability (internal consistency was found to be high in the present study, $\alpha \geq .80$ for all scales) and validity (Matthews et al., 1990). It has been used extensively to measure changes in mood as a result of laboratory based positive mood inductions of a similar design (e.g. Fairclough, vaan der Zwaag, Spiridon, & Westerink, 2014; Thrasher, van der Zwaag, Bianchi-Berthouze, & Westerink, 2011), as well as to demonstrate the different affective properties of positive mood that is high and low in appetitive motivation (Smillie et al., 2012). As the present study is concerned with positive affect, the focus will be on the scales of Energetic Arousal to measure activated positive affect and Hedonic Tone to measure deactivated positive affect.

3.3.2.3. Divergent Thinking

The Alternate Uses Task (Guilford, 1967) was used to measure divergent thinking, which requires participants to list as many uses for three household items (e.g. 'cup') as they can within a five minute period. This task has been used in similar studies that have found positive mood can influence divergent thinking, as well as those demonstrating a relationship between divergent thinking and EBR (Chermahini & Hommel, 2010, 2012). Participants completed two different versions of the task, with one version using the items *cup*, *pencil*, and *chair*; whilst the other using the items *brick*, *shoe*, and *newspaper*.

Guilford (1967) suggests that responses can be scored on four components: originality, fluency, flexibility, and elaboration. However, as flexibility scores are the most empirically and theoretically reliable component in this instance (Chermahini & Hommel, 2010), analysis will focus only on this component of divergent thinking.

For an acceptable response, the use must be conceivable and scores were calculated by summing the number of different categories used across answers for a specific item, such that

two answers from the same category (e.g. '*storing pens*' and '*storing keys*') would be scored one mark between them, whereas two answers from different categories (e.g. '*storing pens*' and '*paperweight*') would be scored one mark each. Therefore, higher scores represent greater flexibility and divergent thinking.

Inter-rater reliability was found to be good, based on a randomly selected 10% sample of the data across mood conditions ($r = \geq .92$, $p \leq .001$).

3.3.2.4. Convergent Thinking

A set of remote associate problems (Bowden & Jung-Beeman, 2003), based on the Remote Associates Test (Mednick, 1962), were used to assess convergent thinking. Participants were presented with 21 items, each consisting of three seemingly unrelated words, (e.g. '*cream*, *skate*, *water'*) and are asked to generate a common associate word that may link the three (e.g. '*ice'*). Based on normative data of mean solution times (Bowden & Jung-Beeman, 2003), a range of items classified as easy, moderate, and hard in difficulty were used. Participants completed two versions of the task (i.e., pre- and post-mood induction), with items used being matched for difficulty across versions.

Participants were given 10min to complete the task, with each correct solution receiving a score of one, such that higher scores represented greater convergent thinking. This task was used as previous studies have demonstrated seemingly contradictory results on the Remote Associates Test, with performance being shown to improve with positive mood inductions (e.g., Rowe et al., 2007), but (non-significant) negative correlations between performance and EBR (Chermahini & Hommel, 2010).

3.3.2.5. EBR

EBR was used as a physiological marker of dopamine activity and was measured using video recordings. Participants were recorded while sitting alone and following instructions to look at a blank computer screen with a central fixation cross for 5min. The first minute was considered to be a period of adaptation and not included in analysis (Borges, Garcia, & Cruz, 2010). Therefore, eye blink frequency was counted in the following 4min, which were divided into 4 x 60sec periods, allowing the mean number of eye blinks per minute to be calculated (Dreisbach et al., 2005). In line with previous studies, registration always occurred during daylight hours, based on findings that EBR is stable during the day (Barbato et al., 2000).

3.3.3. Procedure

Upon arrival to the laboratory, participants completed pre-induction measurements of EBR and a computerised version of UMACL, followed by the Alternate Uses Task and the Remote Associates Test. Instructions were presented on the computer, but participants completed paper and pencil versions of each task. Timings were computer-monitored and an audible beep signalled when the time limit had been reached. Participants then underwent a computerised mood induction, and completed either the mood induction for positive mood high in appetitive motivation or the positive mood low in appetitive motivation. Afterwards participants completed post-induction measurements of EBR, UMACL, the Alternate Uses Task, and the Remote Associates Test. This was followed by completion of a final induction-check measurement of UMACL to ensure that the mood induction carried across both tasks completed following the mood induction.

A Latin square design was used to counterbalance the order for which participants within each mood induction condition completed the Alternate Uses Task and Remote Associates Test, with the version of tasks being completed before and after the induction nested within. The same version of UMACL was completed at all time points, and all of the computerised tasks and measures were presented using SuperLab 5.0 software. The total time for participation was approximately 1 hr and 30 min.

3.4. Results

3.4.1. Data Screening

Due to a technical error, mood scores for both activated and deactivated positive affect were missing for nine participants (five in the low appetitive and four in the high appetitive condition) at the post and induction-check time points, as well as two participants (one in the low appetitive and one high appetitive condition) at the induction-check time point. Also, mood scores for deactivated positive affect were not provided by three different participants: one at pre-induction (low appetitive condition), one at post-induction (low appetitive condition), and one at the induction-check (high appetitive condition). In addition, one participant (high appetitive condition) did not provide mood scores for activated positive affect. Therefore, sample size for the analysis conducted for the mood induction check was reduced to $N = 57$ for activated positive affect and $N = 55$ for deactivated positive affect.

As such a large proportion of data was missing (greater than 10%), multiple imputation was conducted (Bennett, 2001). This is a widely-used technique in which linear regression is performed to estimate missing values (Deng, Chang, Ido, & Long, 2016). Analyses with imputed data (average of five predicted values for each missing data point) did not differ in pattern or significance when compared to those conducted with the missing data excluded. Therefore, the latter is presented below.

EBR was also missing for four participants (three in the high appetitive and one in the low appetitive condition) at both the pre- and post-induction time points, which was due to a technical error. EBR could also not be determined for one participant (high appetitive condition) at the pre-induction time point and two participants (one in the low appetitive and one in the high appetitive condition) at the post-induction time point. Therefore, for analysis comparing EBR pre- and post-induction, the sample size was reduced to $N = 62$.

There was also missing data for the divergent thinking task, which was not completed appropriately by one participant (high appetitive condition) at the pre-induction time point, two participants (one in the high and one in the low appetitive condition) post-induction, and two participants at both time points (one in each condition) Therefore, for analysis comparing divergent thinking pre- and post-induction, the sample size was reduced to $N = 64$.

To determine whether there were any outliers, boxplots were visually examined and z-scores were calculated. Extreme values were defined as those being 1.5 interquartile ranges from the median or with a z-score 3.29 standard deviations above the mean (Tabachnick & Fidell, 2007). Two outliers were detected for deactivated positive affect (one high and one low value in the high appetitive mood condition). To remove the influence of these extreme values, but maintain their position within the data set, these were winsorised to the nearest value (Ghosh & Vogt, 2012), which did not change the overall pattern of results for these analyses. Visual inspection of histograms and Q-Q plots found that data was normally distributed, other than for residuals of composite change scores calculated for the Alternate Uses Task and Remote Associates Test. This was confirmed with a Shapiro-Wilks test, and non-parametric tests were used for analyses with these variables.

Visual examination of scatterplots also determined that linear relationships were observed between all variables for which correlation analysis was performed. For regression analyses, homoscedasticity was examined using scatterplots, and variance of the residuals was determined to be constant. Residuals were also determined to be independent, as tested using

the Durbin-Watson test, with upper critical value set at one and the lower critical value set at three (Wang & Jain, 2003).

3.4.2. Baseline Comparison of Mood Conditions

To ascertain that there were no pre-existing differences between the mood conditions, independent t-tests were conducted to examine pre-induction levels of deactivated and activated positive affect, as well as EBR.

The means and standard deviations for this analysis are displayed in Table 3.1, which demonstrates that there were no differences in positive affect (p's $\geq$ .192). However, there was a marginally significant difference for EBR [$t(62) = -1.97$, $p = .054$, $d = -0.49$], with a greater EBR in the high compared to the low appetitive mood condition [($M = 30.43$, $SD = 19.67$) vs. ($M = 22.22$, $SD = 13.32$].

Table 3.1. *Means and standard deviations for deactivated positive affect, activated positive affect, and EBR in mood conditions at the pre-induction timepoints.*

	Low Appetitive		High Appetitive	
	M	*SD*	*M*	*SD*
Deactivated Positive Affect	25.03	4.14	23.74	4.22
Activated Positive Affect	20.09	4.61	18.66	4.41
EBR	22.22	13.32	30.43	19.67

3.4.3. Mood Induction Check

As there was a sizeable difference in pre-induction EBR for the mood conditions, this variable was taken into account when performing analyses examining the effectiveness of the mood induction. This is because of the possibility that differences in EBR between the mood conditions may have influenced the effectiveness of mood inductions. A median split was conducted with EBR to generate a categorical variable with two levels suitable for this analysis.

3.4.3.1. Deactivated Positive Affect

A 3 (time: pre-induction/post-induction/induction-check) by 2 (mood condition: high appetitive/low appetitive) by 2 (pre-induction EBR: lower/higher) mixed ANOVA was

conducted with deactivated positive affect. Mauchly's test for sphericity was significant, so the Greenhouse Geisser procedure was applied, to correct for an inflation in Type I error (ε=.86).

The results of this ANOVA are summarised in Table 3.2, which demonstrates that the pertinent time by mood condition interaction was significant, whilst the time by mood condition by EBR interaction was not. This suggests that the time by mood condition interaction was not moderated by any pre-induction differences in EBR. All other effects were also found not to be significant ($p \geq .236$).

Table 3.2. *ANOVA results for differences in deactivated positive affect dependant on time, mood conditions, and EBR.*

Effect	df	*F*	*p*	η^2_p
Time	1.75, 82.45	1.47	.236	0.03
Mood	1, 47	1.43	.238	0.03
EBR	1, 47	0.05	.826	0.00
Time by Mood Condition	1.75, 82.45	3.12	.047	0.07
Time by EBR	1.75, 82.45	0.24	.755	0.01
Mood Condition by EBR	1, 47	0.28	.597	0.01
Time by Mood Condition by EBR	1.75, 82.45	0.41	.640	0.01

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in deactivated positive affect within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons ($\alpha = .013$). The means and standard deviations for this analysis are displayed in Figure 3.1.

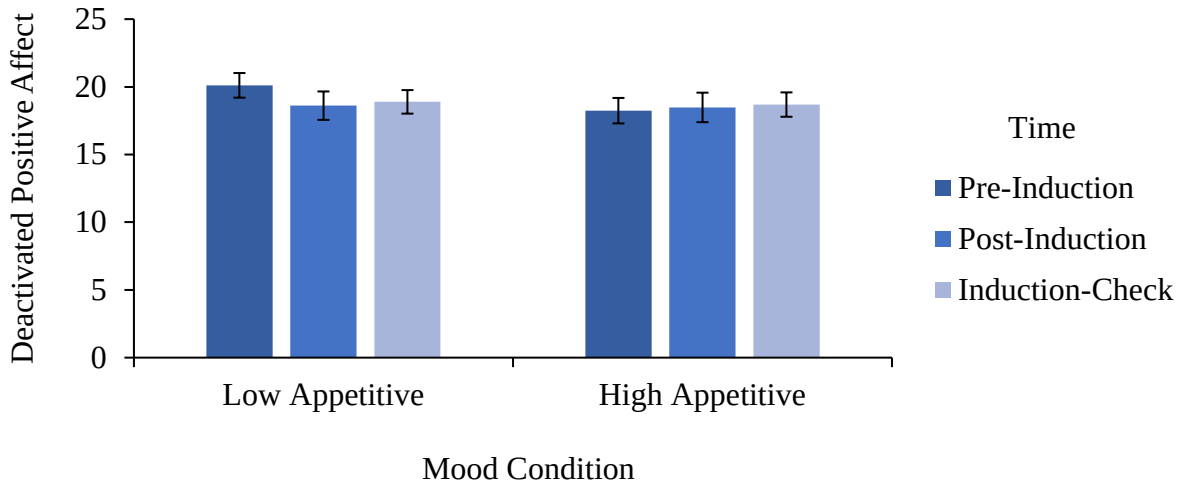


Figure 3.1. *Mean deactivated positive affect at different time points for the mood conditions. Error bars reflect one standard error above and below the mean.*

For the low appetitive condition, Figure 3.1 demonstrates there was a significant decrease in deactivated positive affect [$t(28) = -2.47$, $p = .010$, $d = -0.27$] from pre-induction ($M = 19.90$, $SD = 4.91$) to post-induction ($M = 18.52$, $SD = 5.44$). However, there was no significant difference between the post-induction and induction-check timepoint [$t(27) = -0.23$, $p = .900$, $d = -0.01$]. This suggests that the mood induction was not effective, as an increase in deactivated positive affect was expected.

For the high appetitive condition, Figure 3.1 demonstrates there was no significant difference in deactivated positive affect from pre-induction to post-induction [$t(30) = 0.59$, $p = .281$, $d = 0.10$], or from the post-induction to the induction-check timepoint [$t(28) = -0.34$, $p = .737$, $d = -0.04$].

3.4.3.2. Activated Positive Affect

When examining the effect of the mood induction on activated positive affect, pre-induction EBR was also taken into account in a second 3 (time: pre-induction/post-induction/induction-check) by 2 (mood condition: high appetitive/low appetitive) by 2 (pre-induction EBR: lower/higher) mixed ANOVA.

The results of this ANOVA are summarised in Table 3.3, which demonstrates that the pertinent time by mood condition interaction approached significance, whilst the time by mood condition by EBR interaction did not. This suggests that the time by mood condition interaction was not

moderated by any pre-induction differences in EBR. All other effects were also found not to be significant ($p \geq .168$).

Table 3.3. *ANOVA results for differences in activated positive affect dependant on time, mood condition, and EBR.*

Effect	df	*F*	*p*	η^2_p
Time	2, 96	0.75	.477	0.02
Mood Condition	1, 48	0.28	.601	0.01
EBR	1, 48	1.96	.168	0.10
Time by Mood Condition	2, 96	2.65	.076	0.05
Time by EBR	2, 96	0.41	.666	0.01
Mood Condition by EBR	1, 48	0.60	.168	0.04
Time by Mood Condition by EBR	2, 96	1.76	.178	0.04

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in activated positive affect within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to four multiple comparisons ($\alpha = .013$). The means and standard deviations for this analysis are displayed in Figure 3.2.

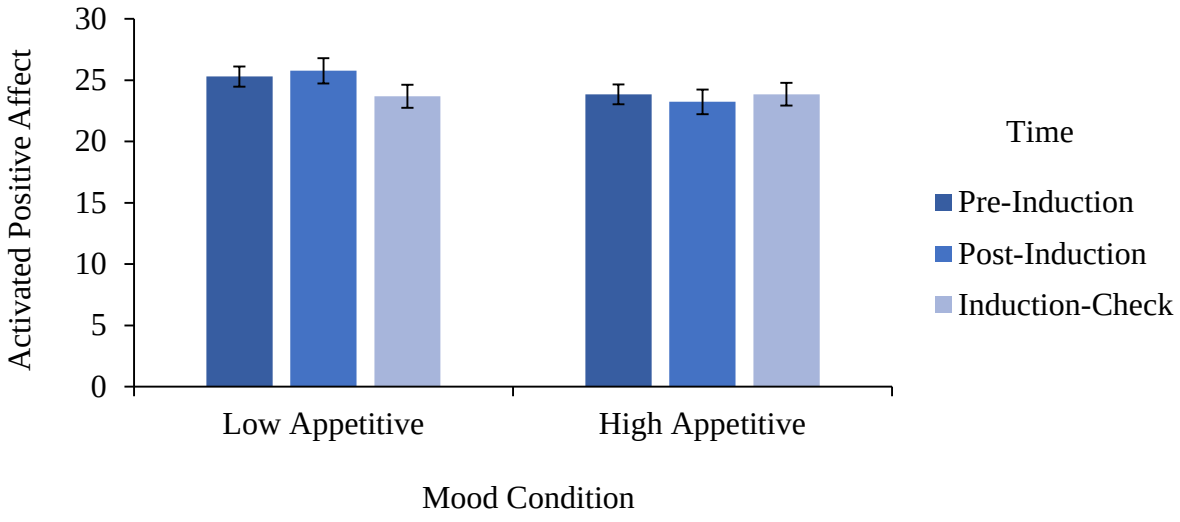


Figure 3.2. *Mean activated positive affect at different time points for the mood conditions. Error bars reflect one standard error above and below the mean.*

For the high appetitive condition, Figure 3.2 demonstrates that there was no significant difference in activated positive affect between any of the timepoints [*t*'s ≤ 1.04, *p*'s $\geq .305$, *d*'s

≤ 0.13]. This suggests that the mood induction was not effective, as an increase in activated positive affect was expected between pre- and post-induction timepoints.

For the low appetitive condition, Figure 3.2 demonstrates that there was no significant difference between pre-induction and post-induction activated positive affect [$t(26) = 0.91$, $p = .187$, $d = 0.13$]. However, there was a significant decrease in activated positive affect from the post-induction ($M = 25.63$, $SD = 4.41$) to the induction-check timepoint ($M = 23.59$, $SD = 4.19$), [$t(26) = -3.52$, $p = .002$, $d = -0.47$].

3.4.4. Effect of Positive Mood and Creativity

Although the mood induction check indicated that this did not influence positive affect as expected, analysis was still conducted as planned to examine the moderating role of appetitive motivation in relation to the influence of positive mood on creativity. This was to allow for the possibility that mood inductions may have resulted in expected changes to positive affect, but that these were not detected by the measure of affect used (i.e., UMACL).

Therefore, separate 2 (time: pre-induction/post-induction) by 2 (mood condition: high appetitive/low appetitive) mixed design ANOVAs were conducted for the creativity measures. The results of this analysis are displayed in Table 3.4.

Table 3.4. *ANOVA results for differences in divergent and convergent thinking dependant on time and mood condition.*

Effect	df	*F*	*p*	η^2_p
Divergent Thinking				
Time	1, 62	0.140	.532	0.01
Mood Condition	1, 62	0.39	.536	0.01
Time by Mood Condition	1, 62	0.11	.738	0.00
Convergent Thinking				
Time	1, 67	0.19	.279	0.02
Mood Condition	1, 67	0.28	.602	0.00
Time by Mood Condition	1, 67	0.11	.745	0.00

However, Table 3.4 shows no significant effects were observed (p's ≥ .279), including for the pertinent time by mood condition interactions.

The means for convergent and divergent thinking performance at different timepoints within mood conditions are displayed in Figure 3.3 and Figure 3.4.

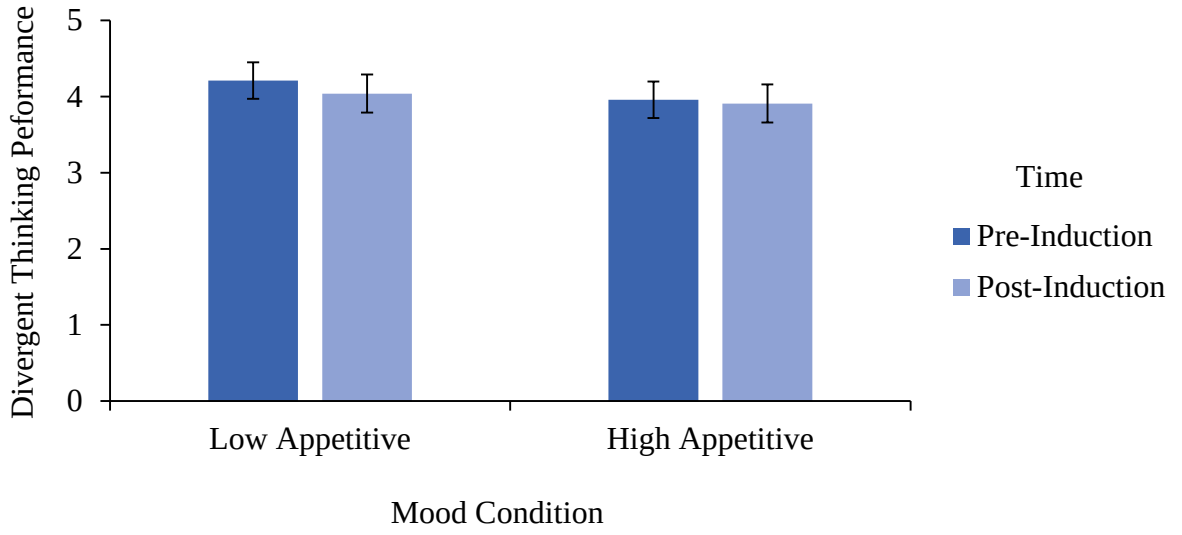


Figure 3.3. *Divergent thinking task performance at different time points for each mood condition. Error bars reflect one standard error above and below the mean.*

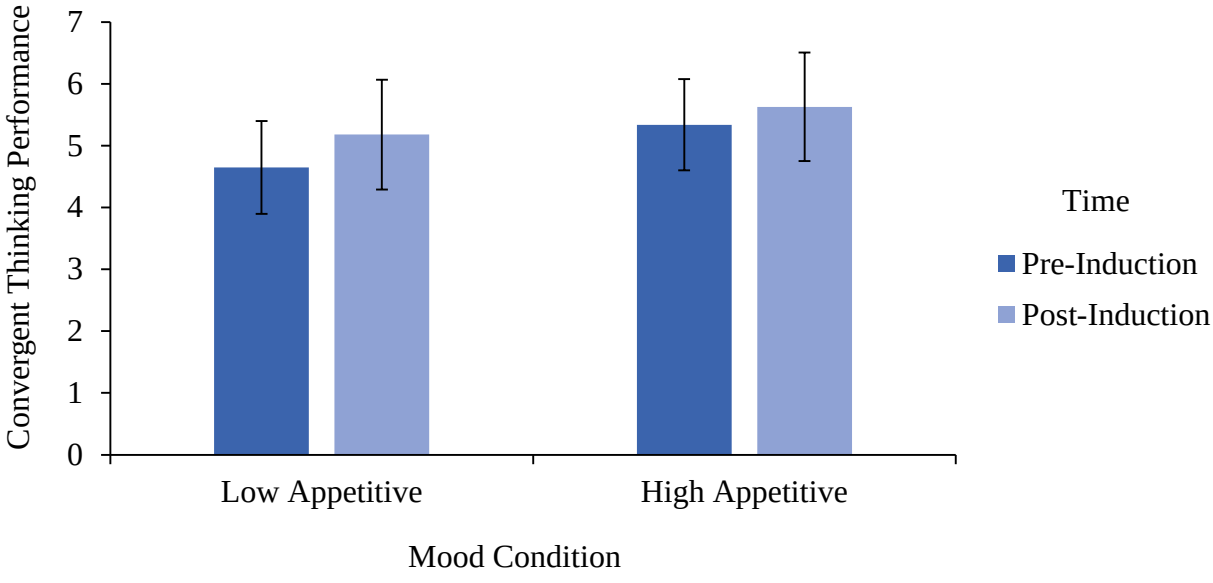


Figure 3.4. *Convergent thinking task performance at different time points for each mood condition. Error bars reflect one standard error above and below the mean.*

Figure 3.3 and Figure 3.4 demonstrate no differential effects for these positive mood inductions on creativity measures. Therefore, these results do not provide any evidence that appetitive motivation moderates the influence of positive mood on creativity (cf. Chermahini & Hommel, 2012), which likely reflects the lack of expected changes in positive affect resulting from the mood induction procedure.

3.4.4.1. Relationships between Positive Affect and Creativity

Exploratory correlation analysis was also conducted to examine relationships between positive activated and deactivated affect and creativity.

For both the pre- and post-induction timepoints, there was no evidence of any correlation between divergent thinking performance and deactivated positive affect [r's $\leq .01$, p's $\geq .400$]. However, slight trends for weak negative correlations were somewhat closer to significance for activated positive affect [r's $\geq -.21$, p's $\leq .108$).

For both the pre- and post-induction timepoints, there was also no evidence of any correlation between convergent thinking performance and deactivated positive affect [r's $\leq -.02$, p's $\geq .932$]. This was also the case for activated positive affect at the post-induction timepoint [$r(60) = .01$, $p = .954$]. However, a weak negative correlation approached significance at the pre-induction timepoint [$r(69) = -.23$, $p = .062$].

Although non-significant, these results provide some evidence that increases in activated positive affect (but not deactivated positive affect) were related to divergent thinking performance. This was also the case for performance on the convergent thinking task, but only at the pre-induction timepoint.

3.4.5. Effect of Positive Mood and EBR

Again, despite the fact that the mood induction procedure was not found to influence affect as expected, analysis was still conducted as planned to examine the moderating role of appetitive motivation in relation to the influence of positive mood on EBR. This allows for the possibility that mood inductions may have resulted in the expected changes to positive affect, but that these were not detected by the measure of affect (i.e., UMACL)

A 2 (time: pre-induction/post-induction) by 2 (mood condition: high appetitive/low appetitive) mixed design ANOVA was conducted for EBR. The results of this analysis are displayed in Table 3.5.

Table 3.5. *ANOVA results for differences in EBR dependant on time and mood condition.*

Effect	df	*F*	*p*	η^2_p
Time	1, 59	3.71	.059	0.06
Mood Condition	1, 60	1.49	.227	0.03
Time by Mood Condition	1, 59	5.66	.021	0.09

Table 3.5 shows that a main effect of time approached significance, such that EBR increased from the pre-induction (*M* = 26.44, *SD* = 17.48) to the post-induction timepoint (*M* = 28.71, *SD* = 16.93). There was also a main effect of mood induction, such that EBR was greater for the high appetitive (*M* = 32.48, *SD* = 16.58) compared to the low appetitive mood condition (*M* =22.67, *SD* = 16.55). However, the pertinent interaction effect for time by mood condition was not found to be significant.

The means for EBR at different timepoints within the mood conditions can be seen in Figure 3.5, which demonstrates no differential changes in EBR for the mood conditions.

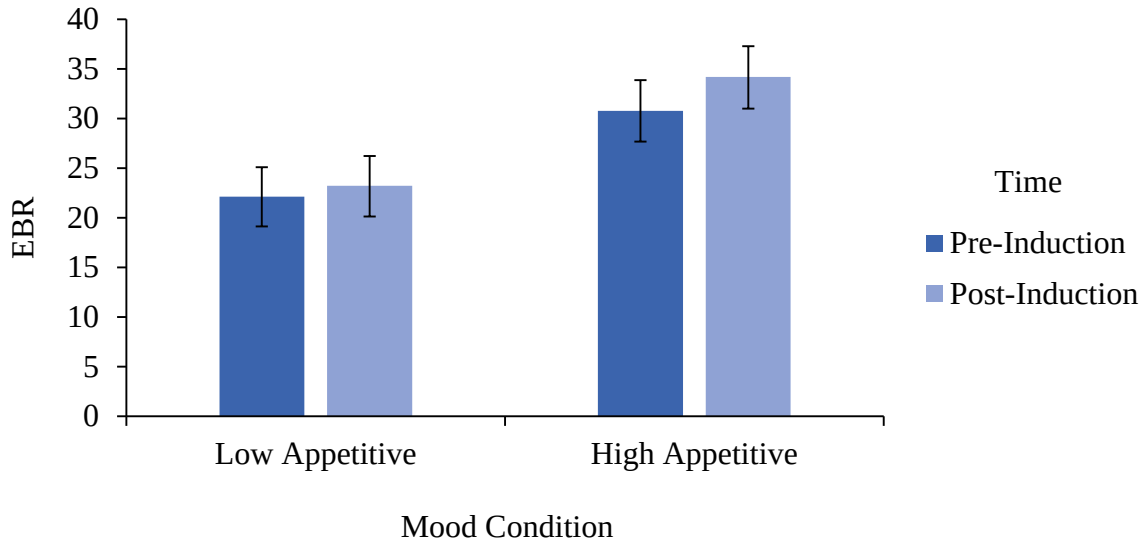


Figure 3.5. *EBR at different time points for each mood condition. Error bars reflect one standard error above and below the mean.*

3.4.5.1. Relationships between Positive Affect and EBR

Exploratory correlations were performed to examine the relationships between activated and deactivated positive affect and EBR.

At the pre-induction timepoint, a weak negative correlation for EBR and activated positive affect was found to be significant [$r(64) = -.27$, $p = .030$], and a similar correlation also approached significance for deactivated positive affect [$r(63) = -.22$, $p = .081$].

However, at the post-induction timepoint, weak negative relationships did not reach significance for EBR and activated positive affect [$r(56) = -.18$, $p = .180$], or deactivated positive affect [$r(55) = -.15$, $p = .264$].

Therefore, these results provide some evidence that there may be a negative relationship between positive affect and EBR, although this does not seem to be different for activated and deactivated positive affect.

3.4.6. Relationships between Pre-Induction EBR and Creativity

To examine the fit for relationships between pre-induction EBR and divergent and convergent thinking performance, separate regression analyses were conducted with pre-induction variables. To avoid potentially problematic high multicollinearity with the quadratic term, the variables were centred prior to entry into regression models (Aiken & West, 1991). The quadratic term was calculated by squaring the centred value for EBR. For both sets of analyses, EBR was entered in the first step to test a linear fit, and the quadratic term was then entered in the second step. Coefficients for this analysis are displayed in Table 3.6.

Table 3.6. *Coefficients for tests of linear and quadratic relationships between EBR and divergent and convergent thinking task performance.*

	Linear	Quadratic
	β	β
Divergent Thinking	-0.13	-0.11
Convergent Thinking	-0.10	-0.21

A scatterplot with regression lines for linear and quadratic models for divergent thinking is displayed in Figure 3.6.

.

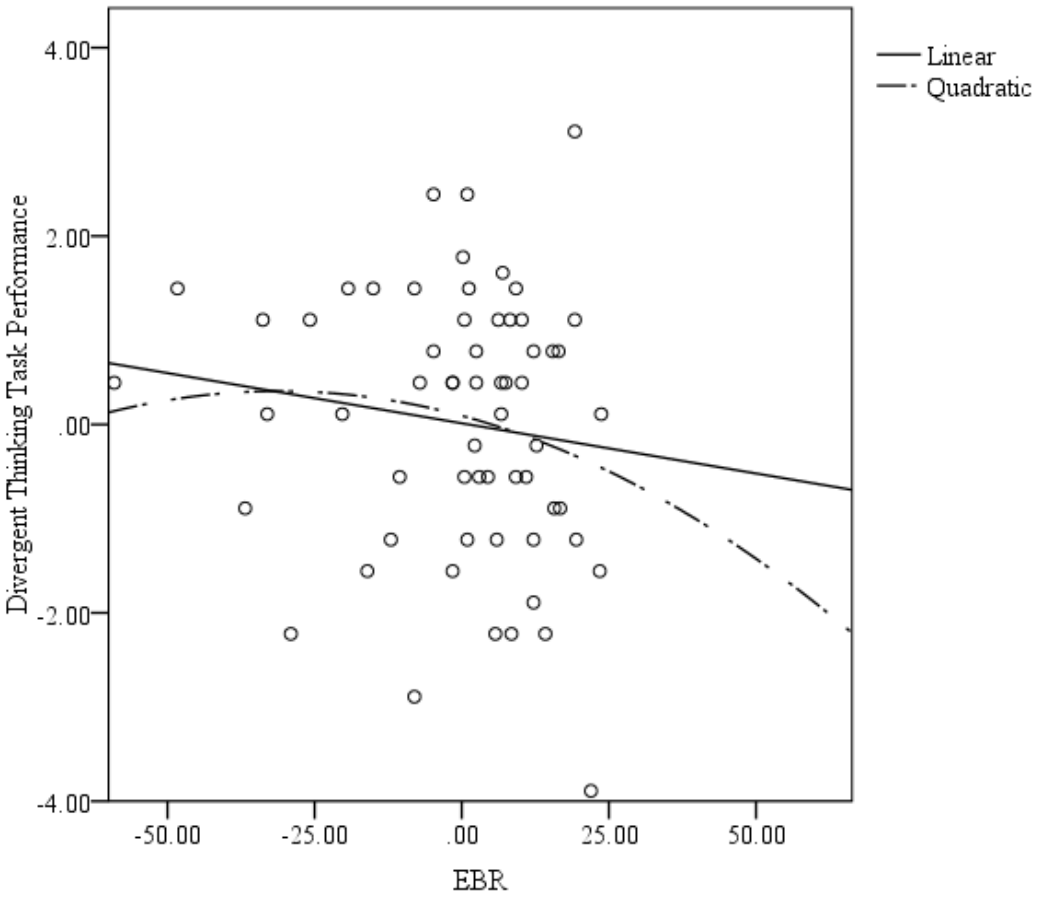


Figure 3.6. *Pre-induction (i.e., baseline) divergent thinking task performance as a function of EBR.*

Figure 3.6 shows some evidence of a trend towards a negative linear relationship between EBR and divergent thinking performance. However, a linear model was found not to be significant [R^2= .02, F(1,60) = 1.04, p = .311], and adding the quadratic term did not explain additional variance in this model [ΔR^2= .01, F(2,60) = .71, p = .498].

A scatterplot with regression lines for linear and quadratic models is displayed in Figure 3.7 for convergent thinking.

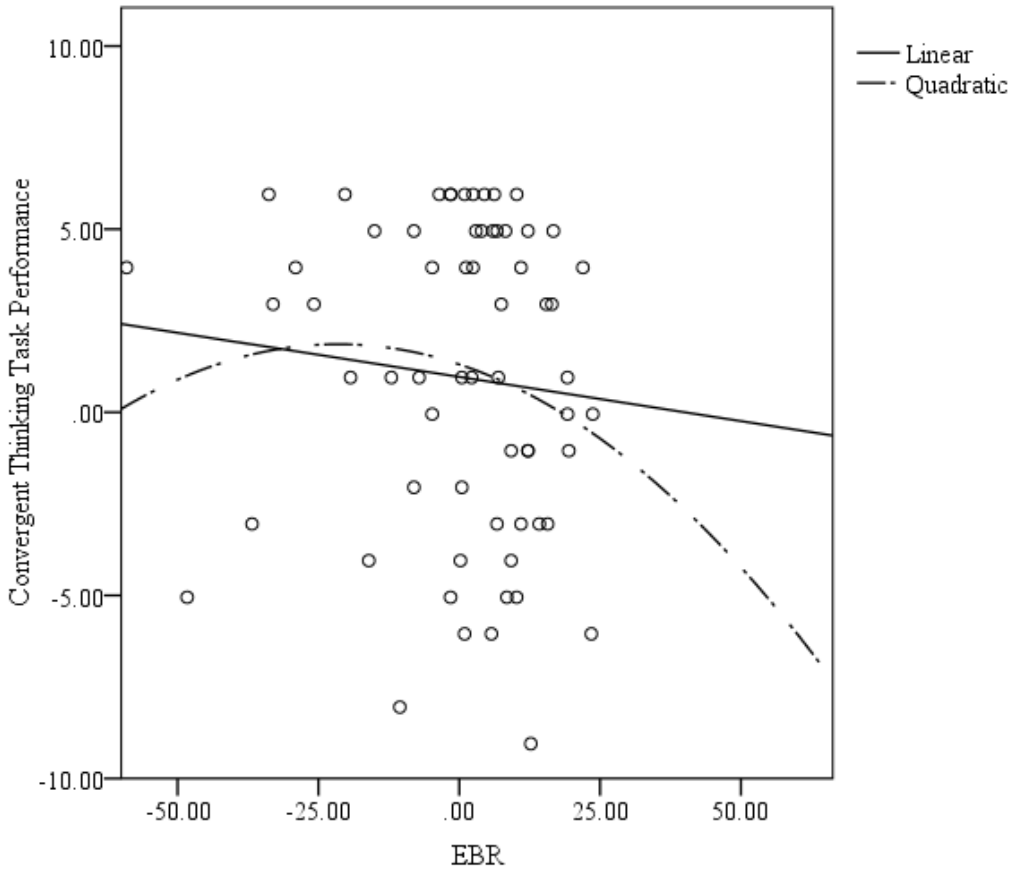


Figure 3.7. *Pre-induction (i.e., baseline) convergent thinking task performance as a function of EBR.*.

Figure 3.7 also shows some evidence of a trend towards a negative linear relationship between EBR and convergent thinking performance. However, a linear model was, again, found not to be significant [R^2= .01, F(1,63) = 0.59, p = .447], and adding the quadratic term did not explain additional variance in the model [ΔR^2= .01, F(2,63) = 0.70, p = .500].

These findings are not in line with those of Chermahini and Hommel (2010, 2012), where a quadratic fit was found to significantly fit the relationship between EBR and divergent thinking performance. However, these authors did find some evidence of a trend towards a negative linear relationship for convergent thinking performance.

3.4.7. Changes in EBR, Positive Affect, and Creativity

The relationship between changes in creativity and changes in positive affect and EBR following the mood induction were examined by calculating composite change scores (subtracting pre-induction scores from post-induction values) for activated positive affect,

deactivated positive affect, EBR, and divergent and convergent thinking performance (cf. Chermahini & Hommel, 2012).

Correlations between changes in positive affect and changes in creativity were examined, as well as between changes in EBR and changes in creativity, using Spearman's rho as the correlation coefficient because residuals were not normally distributed for these variables. A Bonferroni correction was also applied to correct for inflated Type I error due to two multiple comparisons ($\alpha = .025$) and the results can be seen in Table 3.7.

Table 3.7. *Correlation coefficients and probability values for changes in creativity, changes in positive affect, and changes in EBR*

	Divergent Thinking		Convergent Thinking	
	r_s	p	r_s	p
Activated Positive Affect	-.03	.393	.02	.450
Deactivated Positive Affect	-.03	.408	.16	.115
EBR	-.21	.060	-.16	.106

Table 3.7 demonstrates that there were no significant correlations between changes in positive affect and changes in divergent or convergent thinking (p's $\geq .115$). However, there was a trend towards significance for a negative correlation between change in EBR and change in divergent thinking. This was also the case for change in EBR and change in convergent thinking performance, although this was not as close to significance.

Therefore, these results provide no evidence of a relationship between changes in positive affect and creativity, but suggest that an increase in EBR may be related to a decrease in creativity, and that this was most reliable for divergent thinking task performance.

3.4.8. Moderating Effect of Pre-Induction EBR on Positive Mood and Creativity

3.4.8.1. Divergent Thinking

To examine the moderating role of EBR on the influence of positive mood on divergent thinking a 2 (time: pre-induction/post-induction) by 2 (mood condition: high appetitive/low appetitive) by 2 (pre-induction EBR: lower/higher) mixed ANOVA was conducted. Levene's test for homogeneity of variance was significant for the mood conditions at the post-induction timepoint, suggesting that there may not be equal variances between groups. However, this

should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups when cell sizes are equal (Zimmerman, 2004).

The results of this analysis are displayed in Table 3.8, which shows that there were no significant main or interaction effects (*p*'s ≥ .233), including for the pertinent time by mood condition by pre-induction EBR interaction.

Table 3.8. *ANOVA results for differences in divergent thinking performance dependant on time, mood condition, and pre-induction EBR.*

Effect	df	*F*	*p*	η^2_p
Time	1, 55	0.00	.970	0.00
Mood Condition	1, 55	0.49	.487	0.01
EBR	1, 55	0.84	.364	0.02
Time by Mood Condition	1, 55	0.05	.818	0.00
Time by EBR	1, 55	1.46	.233	0.03
Mood Condition by EBR	1, 55	0.00	.970	0.00
Time by Mood Condition by EBR	1, 55	0.90	.347	0.02

The lack of lack of interaction is confirmed by examining Figure 3.8, which displays the means for divergent thinking performance at different timepoints within mood conditions.

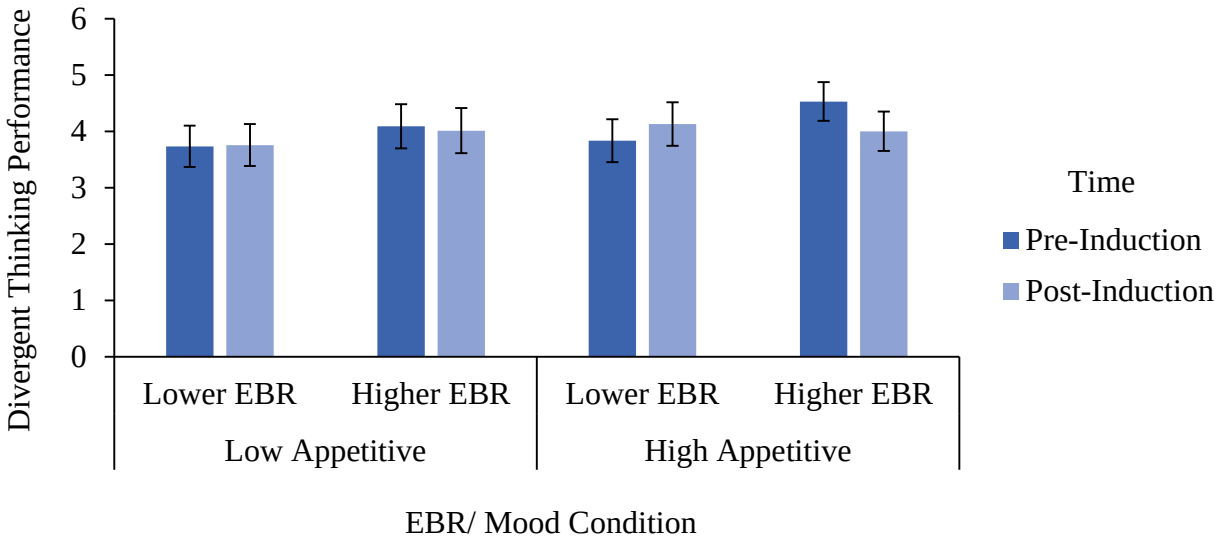


Figure 3.8. *Divergent thinking task performance as a function of time, pre-induction EBR, and mood condition. Error bars reflect one standard error above and below the mean*

Although common practice in research examining EBR, dictomising this variable by performing a median split may be problematic because it results in a loss of statistical power, which can increase the chance of Type II error (Aiken & West, 1991). Therefore, regression analysis was also conducted to examine whether pre-induction EBR moderated the effect of the positive mood inductions on divergent thinking.

Post-induction divergent thinking was entered as the dependent variable. In the first step, pre-induction divergent thinking and pre-induction EBR were entered as continuous predictor variables. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect the low (=0) and high appetitive (=1) conditions. In the second step, a product term was also entered, to reflect the interaction between pre-induction EBR and mood condition. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

There was a significant overall model effect at step one [R^2= .23, F(3,51) = 5.08, p = .004]. Individual predictors for this model are displayed in Table 3.9, which demonstrates that only pre-induction divergent thinking significantly predicted post-induction divergent thinking scores.

Table 3.9. *Coefficients and significance values for individual predictors in regression models for moderation of post-induction divergent thinking by mood condition and pre-induction EBR*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Divergent thinking	.11	.12	.48	3.85	<.001
Mood Condition	-.10	.35	-.038	-.29	.770
EBR	.00	.01	.04	.29	.776
Step 2					
Divergent thinking	.46	.12	.48	3.85	<.001
Mood Condition	-.12	.36	-.04	-.34	.739
EBR	.01	.02	.15	.65	.517
Mood Condition by EBR	-.01	.02	-.13	-.60	.552

Importantly, no additional variance was explained by adding the interaction term for pre-induction EBR and mood condition [ΔR^2= .01, F(1,50) = .36 p = .552].

Therefore, these results are in line with the finding that pre-induction EBR did not moderate the effect of positive mood condition on divergent thinking in the ANOVA analysis above (Table 3.8).

3.4.8.2. Convergent Thinking

To examine the moderating role of EBR on the influence of positive mood on convergent thinking a 2 (time: pre-induction/post-induction) by 2 (mood condition: high appetitive/low appetitive) by 2 (pre-induction EBR: lower/higher) mixed ANOVA was conducted.

The results of this analysis are displayed in Table 3.10, which demonstrates that the pertinent time by mood condition by EBR interaction was marginally significant, whilst all other main and interaction effects were not significant ($p \geq .259$).

Table 3.10. *ANOVA results for differences in convergent thinking performance dependant on time, mood condition, and pre-induction EBR.*

Effect	df	*F*	*p*	η^2_p
Time	1, 60	1.01	.320	0.02
Mood Condition	1, 60	1.30	.259	0.02
EBR	1, 60	1.02	.316	0.02
Time by Mood Condition	1, 60	0.08	.780	0.00
Time by EBR	1, 60	0.09	.894	0.00
Mood Condition by EBR	1, 60	0.44	.511	0.01
Time by Mood Condition by EBR	1, 60	4.06	.049	0.06

Therefore, planned contrasts were conducted using simple effects analysis with paired t-tests. A Bonferroni correction was used to correct for inflated Type I error due to four multiple comparisons ($\alpha = .013$). The means of this analysis are displayed in Figure 3.9.

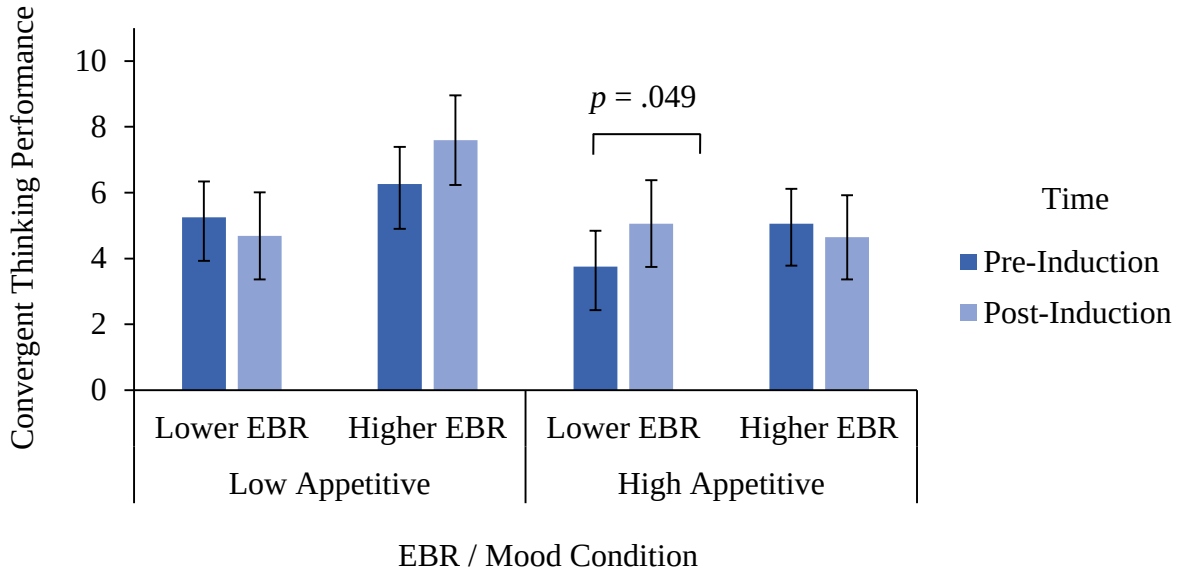


Figure 3.9. *Convergent thinking task performance as a function of time, pre-induction EBR, and mood condition. Error bars reflect one standard error above and below the mean.*

For the low appetitive mood condition, differences in convergent thinking performance were not dependent on EBR [*t*'s ≤ 1.36, *p*'s ≥ .097, *d*'s ≤ 0.29].

However, for the high appetitive condition, there was a pattern, which did not reach significance with the Bonferroni correction, towards an increase in convergent thinking performance for those with a lower EBR (M = 6.20, SD = 4.90 to M = 7.33, SD = 5.90), [$t(14)$ = 1.77, p = .049, d = 0.21]. In contrast, no significant difference was found for those with a higher EBR [$t(15)$ = -0.59, p = .566, d = -0.12].

Regression analysis was also conducted to examine whether pre-induction EBR moderated the effect of the positive mood inductions on convergent thinking.

Post-induction convergent thinking was entered as the dependent variable. In the first step, pre-induction convergent thinking and pre-induction EBR were entered as continuous predictor variables. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect the low (=0) and high appetitive (=1) conditions. In the second step, a product term was also entered, to reflect the interaction between pre-induction EBR and mood condition. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

There was a significant overall model effect at step one [R^2= .62, $F(3,60)$ = 32.70, p < .001]. Individual predictors for this model are displayed in Table 3.11, which demonstrates that only

pre-induction convergent thinking significantly predicted post-induction convergent thinking scores.

Table 3.11. *Coefficients and significance values for individual predictors in regression models for moderation of post-induction convergent thinking by mood condition and pre-induction EBR*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Convergent thinking	.93	.10	.78	9.54	<.001
Mood Condition	.05	.85	.00	.05	.958
EBR	-.02	.03	-.07	-.90	.372
Step 2					
Convergent thinking	.93	.10	.78	9.83	<.001
Mood Condition	2.77	1.51	.27	1.83	.072
EBR	.05	.04	.17	1.22	.226
Mood Condition by EBR	-.11	.05	-.44	-2.15	.036

However, in line with the ANOVA analysis displayed above (Table 3.10), additional variance was explained by adding the interaction term for pre-induction EBR and mood condition [ΔR^2= .03, $F(1,59) = 4.62$, $p = .036$].

Table 3.11 demonstrates that, in addition to pre-induction convergent thinking, the pre-induction EBR and mood condition interaction variable significantly predicted post-induction convergent thinking. Examination of the coefficients suggests that a lower EBR at baseline was associated with enhanced convergent thinking at the post-induction timepoint, only in the high appetitive condition. This is in line with the planned contrasts displayed in Figure 3.9, which were conducting using t-tests with pre-induction EBR as a dictonomus variable.

Therefore, these results suggest that pre-induction EBR may possibly moderate the influence of positive mood only on convergent thinking. This was not in line with hypotheses, and caution must be taken when interpreting this finding, due to failure to find evidence that the mood induction was effective.

3.5. Discussion

The primary aim of this study was to examine whether appetitive motivation moderated the influence of positive mood on creativity. Mood inductions were used to elicit positive mood,

which was either high or low in appetitive motivation. To ensure effectiveness, mood was measured at different time points, and distinct patterns in affective characteristics were expected to result from the inductions (Depue & Collins, 1999; Depue & Morrone-Strupinsky, 2005). For the low appetitive condition, an increase only in deactivated positive affect was expected to occur as a result of the induction, whilst for the high appetitive condition, an increase in only activated positive affect was expected to occur, reflecting a positive mood state with a positive valence and a high level of activation. However, contrary to expectations, it was found that there were no significant increases in activated or deactivated positive affect as a result of the mood inductions in either of the conditions.

3.5.1. Mood Induction Procedure

The finding that the mood induction did not result in the anticipated increases in positive affect was surprising, as this procedure was adapted from previous studies that have successfully used these mood inductions to elicit positive mood states that are high and low in appetitive motivation (e.g., Smillie et al., 2012). Like Smillie et al. (2012), the present study utilised a computerised induction with the same stimuli (music and vignettes) and instructions, and participants completed the mood inductions for a similar length of time. However, O. J. Robinson, Grillon, and Sahakian (2012) suggest that for mood inductions to be effective, participants should: i) use headphones when listening to music, and ii) be alone throughout the mood induction procedure. Although it is unclear whether these procedural aspects were implemented by Smillie et al. (2012), as they were not applied in the present study, this may help to explain null findings in relation to the effectiveness of the mood induction.

O. J. Robinson et al. (2012) also suggest that changes in affect during mood inductions should be assessed using a visual analogue scale. This requires participants to indicate their mood on a 100mm horizontal line, representing a scale from zero to one hundred. The measure used within the present study – the UMACL – requires participants to indicate their mood on a scale from one to four. Compared to this measure, using a visual analogue scale may provide a much more sensitive measure for mild changes in mood, as may be expected to result from mood inductions. Although Smillie et al. (2012) demonstrated significant changes for activated and deactivated affect for high and low appetitive mood inductions using the UMACL, the sample size used in this study was a lot larger than was used in the present study (c.f., $N = 107$ vs. $N = 51$), which may have allowed greater statistical power for smaller changes in mood to be observed.

Participants in Smillie et al.'s (2012) study also completed mood inductions followed directly by a mood measure, whereas participants in the present study had EBR recorded for a five-minute period before mood was assessed. During this period, participants were required to look at a blank computer screen with a cross-hair in the centre, so it may be the case that any changes in mood that occurred as a result of the mood induction dissipated during this period of rest. There was a good rationale for using this design, as it was similar to the procedure followed by Chermahini and Hommel (2012). In this study, participants completed a mood induction, followed by a six-minute recording of EBR, and then completed a mood measure. However, the mood induction was demonstrated to result in an increase in positive affect, unlike in the present study. Perhaps it may have been the case that this study utilised a more effective mood induction procedure overall, which may have prevented changes in mood from dissipating during EBR recording.

In addition, Smillie et al.'s (2012) study was conducted to examine the influence of personality on these positive mood inductions. Therefore, prior to undergoing the mood inductions, participants simply completed a handful of personality questionnaires. However, the present study required (in addition to EBR recording), that participants completed the divergent and convergent thinking tasks prior to mood inductions. This allowed within-subject comparisons after the induction, again following a similar design to Chermahini and Hommel's (2012) study. However, this study only examined performance on the divergent thinking task, whilst the present study also required participants to complete a convergent thinking task. Therefore, the additional ten minutes that were required to complete the convergent thinking task prior to the induction may have left participants more fatigued in the present study (cf. Chermahini & Hommel's, 2012, single divergent thinking task), which could have prevented effective engagement with the mood induction procedure.

3.5.2. Positive Mood and Creativity

Despite the lack of expected changes in mood resulting from the mood inductions, the influence of positive mood was still examined in relation to creativity tasks. Based on the motivational intensity model (Gable & Harmon-Jones, 2010), it was hypothesised that the low appetitive condition would result in an increase in only divergent thinking performance, whilst the high appetitive condition would result in an increase in only convergent thinking performance. However, appetitive motivation was not found to moderate the influence of positive mood on creativity, and there was no effect of the positive mood inductions on divergent or convergent

thinking tasks in any way, including an overall effect across both conditions. As previous findings have demonstrated that positive mood is related to performance on these tasks (e.g. Chermahini & Hommel, 2012; Rowe et al., 2007), it is likely that the lack of observed effects in the present study is due to the ineffectiveness of the mood induction.

Even though it seems that the mood induction may have been ineffective in inducing the expected changes to positive affect, the relationships between positive affect and creativity can still be examined with validity. It could be expected that deactivated positive affect may be positively associated with divergent thinking, whilst convergent thinking may be positively associated with activated positive affect. This is based on the affective qualities described for positive mood states that are high and low in appetitive motivation (Depue & Collins, 1999), and the expected effects of these states on creativity based on the motivational intensity model (Gable & Harmon-Jones, 2010). However, whilst deactivated positive affect was not found to be related to performance on either of the creativity tasks, there was preliminary, limited evidence of a general (but non-significant) pattern, which suggested that activated positive affect was negatively related to performance on the divergent thinking task, at both the pre-induction and post-induction time points.

The finding of a negative relationship between activated positive affect and divergent thinking suggests that as activated positive affect (i.e., experienced during positive mood states that are high in appetitive motivation) increases, divergent thinking performance decreases. This does not directly support hypotheses relating to the effect of positive mood on divergent thinking (i.e., enhanced performance only for positive mood low in appetitive motivation). However, it is somewhat in line with the expectation of an antagonistic relationship between flexibility and stability in cognition (Goschke, 2000). Specifically, if positive mood high in appetitive motivation results in narrower and more stable cognition, this may be unfavourable for performance on divergent thinking tasks, which require broader and more flexible cognition. However, the present study found no relationship between deactivated positive affect and divergent thinking task performance at any of the time points.

Perhaps one explanation for the lack of correlation between deactivated positive affect and divergent thinking may be due to the use of the UMACL to assess affect. This measure assesses affect using three dimensions: Tense Arousal, Energetic Arousal, and Hedonic Tone. The factor for Energetic Arousal takes into account both the valence and activation properties of affect, giving a good measure of activated positive affect. However, Hedonic Tone only measures valence, and does not take into account the activation of affect. Therefore, this may not provide

an accurate measure of deactivated positive affect. The 12-Point Affect Circumplex (12-PAC; Yik et al., 2011) model and associated scale may be more appropriate here. This has two dimensions that assess valence and activation in affect, as well as a further four dimensions based on combined levels of these properties. Therefore, this may provide a more finely grained analysis of activated and deactivated positive affect.

There is little previous research examining the relationships between state positive mood and divergent thinking task performance (cf. the effect of positive mood inductions) However, one study conducted by Vosburg (1998) examined the relationship between deactivated positive affect and divergent thinking performance in the absence of a mood induction, finding a small positive correlation that approached significance. This finding is in line with the motivational intensity model, in terms of suggesting that positive affect low in appetitive motivation (i.e., deactivated positive affect) is related to broader and more flexible cognition. Although this study only measured deactivated positive affect, it seems to compliment the trend towards a negative relationship between activated positive affect and divergent thinking task performance that was observed in the present study.

The present study also found a (non-significant) pattern suggesting that there may be a negative relationship between activated positive affect and convergent thinking performance – although this was observed only at the pre-induction time point. This is the opposite to the relationship that may have been expected, as it suggests that an increase in activated positive affect is detrimental to convergent thinking. This is not consistent with the motivational intensity model, which suggests that narrower and more stable cognition (i.e., as required in convergent thinking tasks) is promoted by positive mood that is high in appetitive motivation. In combination with the findings of a negative relationship between activated positive affect and divergent thinking, this seems to suggest that this mood state is beneficial to creativity regardless of whether divergent and convergent thinking processes are involved in task performance. However, this is inconsistent with the premise in this study.

Perhaps one an explanation can be found in the choice of measure used to assess convergent thinking used in the present study – the Remote Associates Test, which requires two stages: searching semantic knowledge structures for possible candidate solutions and identifying the appropriate solution (Smith et al., 2012). The search for possible solutions has been demonstrated to rely on associative processing, which is the most substantial component underlying divergent thinking (C. S. Lee et al., 2014), whilst the identification of the most appropriate solution involves testing each candidate solution against the constraints of the

problem, which is suggested to be the common link with other tasks requiring convergent thinking (Kenett, Anaki, & Faust, 2014). Therefore, activated positive mood may be negatively related to performance on the Remote Associates Test because it is detrimental to the divergent thinking component of this task. However, this explanation is undermined by the fact that only small correlations were demonstrated for the Remote Associates Test and the Alternate Uses Task used in the present study ($r \leq .20$).

In their study, Chermahini and Hommel (2012) found that increases in positive affect following the mood induction were associated with increases in divergent thinking task performance. Therefore, changes in positive mood and performance on creativity tasks were examined in the present study, and it was hypothesised that these findings would be replicated only for deactivated positive affect. Although not previously examined, a similar relationship was hypothesised for increases in activated positive affect and convergent thinking task performance. However, no significant relationships were found between changes in positive affect and performance on either of the creativity tasks. This seems surprising considering the fact that some relationships were observed between positive affect (assessed separately at pre- and post-induction timepoints) and performance on these tasks. However, perhaps this may be due to less variability in changes in mood due to the likely ineffectiveness of the mood induction procedure.

3.5.3. Positive Mood and EBR

The second aim of this study was to explore the possible neurobiological mechanisms underlying the association between positive mood and creativity using indirect measures of neurophysiological activity (i.e., EBR). The influence of positive mood on EBR was examined by comparing this before and after positive mood inductions that were high and low in appetitive motivation. Chermahini and Hommel (2012) previously demonstrated that a positive mood induction resulted in an increase in EBR, which was suggested to reflect greater dopamine activity in the nigrostriatal pathway. However, pharmacological studies have found that increasing dopamine activity associated with the nigrostriatal and mesocorticolimbic pathways both result in increased EBR (e.g., Elsworth et al., 1991). As positive affect high in appetitive motivation may be related to dopamine activity in the mesocorticolimbic pathway (Depue & Collins, 1999; Knutson & Cooper, 2005), the present study adopted an exploratory approach to examine the effect of positive mood inductions on EBR in the present study.

However, no effect of positive mood on EBR was found, which is likely due to the failure of the mood induction procedure.

Despite this, the relationships between positive affect and EBR were explored, and both activated and deactivated positive affect were found to be negatively related to EBR (only at the pre-induction timepoint). A similar relationship between EBR and positive affect associated with moods that are high and low in appetitive motivation may suggest that both of these mood states may be associated with a decrease in EBR. This is not in line with pharmacological studies (e.g., Elsworth et al., 1991), which have demonstrated that increased activity of the mesocorticolimbic and nigrostriatal pathways (assumed to be related to positive mood high and low in appetitive motivation) results in increased EBR. Furthermore, the use of the UMACL may have caused confusion when interpreting results, as the Hedonic Tone factor (used to assess deactivated positive affect) may more accurately reflect positive valence. Therefore, the relationship between this and EBR may only be symptomatic of a negative relationship between EBR and activated positive affect.

Models of cognitive control suggest that activity of the nigrostriatal and mesocorticolimbic systems are reciprocal, such that broad and flexible cognition occurs due to an increase in nigrostriatal activity (and reciprocal decrease in mesocorticolimbic activity), whilst narrower and more stable cognition occurs due to an increase in mesocorticolimbic activity (and reciprocal decrease in nigrostriatal activity) (Cools & D'Esposito, 2011). This may explain the negative relationship that was observed between EBR and activated positive affect, if EBR is assumed to reflect dopamine activity in the nigrostriatal pathway, as suggested by Chermahini and Hommel (2010, 2012). Furthermore, if a decrease in nigrostriatal activity occurs for activated positive affect (i.e., assumed to result in the attenuation of broader/more flexible cognition), this may be detrimental to divergent thinking. Therefore, this may explain the negative relationship observed between activated positive affect and divergent thinking in the present study (discussed above).

3.5.4. EBR and Creativity

Chermahini and Hommel (2010) previously demonstrated that baseline EBR was differentially related to divergent and convergent thinking tasks. Whilst a non-linear inverted U-shaped relationship existed for divergent thinking performance, convergent thinking task performance was found not to be related to EBR, but a non-significant negative trend between these variables was observed. The authors suggested that EBR reflected greater nigrostriatal dopamine

activity, which is in line models of cognitive control suggesting that flexibility is mediated by an increase in dopamine in the basal ganglia, and that a reciprocal relationship exists between this and activity of the mesocorticolimbic pathway, which mediates stability in cognitive control (Cools & D'Esposito, 2011). The present study also examined the relationship between EBR and creativity, and Chermahini and Hommel's (2010) findings were expected to be replicated (i.e., an inverted U-shape for EBR and divergent thinking, and no relationship or a possible negative trend for convergent thinking).

Hypotheses were formulated with the relationship between baseline EBR and creativity (but not for the effect of mood inductions on EBR), as when measured at rest, EBR is suggested to primarily reflect activity of the nigrostriatal dopamine system (Jongkees & Colzato, 2016) (but following manipulations may also reflect activity of the mesocorticolimbic system – Elsworth et al., 1991). No relationship was found between convergent thinking and EBR, which is in line with the suggestion that narrower and more stable cognition is mediated by dopamine activity in the prefrontal cortex (Durstewitz & Seamans, 2008), as opposed to the basal ganglia. However, there was no evidence of a negative trend, which would be expected, based on the reciprocal relationship between nigrostriatal and mesocorticolimbic activity (Cools & D'Esposito, 2011). There was also no evidence of a relationship between EBR and divergent thinking (neither linear nor quadratic), which is not in line with hypotheses.

The finding that pre-induction EBR and divergent thinking task performance were unrelated is not in line with suggestions that broad and flexible cognition is mediated by nigrostriatal dopamine activity (Frank & O'Reilly, 2006). This is surprising as Chermahini and Hommel (2010) have demonstrated an inverted U-shape relationship between these variables in two separate experiments. Furthermore, this has also been replicated on a third occasion in a further study conducted by the same authors (Chermahini & Hommel, 2012). In their original study, Chermahini and Hommel (2010) combined analyses from the two separate experiments, which produced the same pattern of results. Sample size in the present study matches the sample size for this combined analysis (N = 69 cf., 68), and original sample sizes, for the empirical studies demonstrating this relationship, were in fact much lower (N < 35). Therefore, inconsistencies with previous findings cannot be attributed to differences in statistical power.

3.5.5. EBR, Positive Mood, and Creativity

Chermahini and Hommel (2012) also found that increases in EBR following a positive mood induction were correlated with increases in divergent thinking, which was suggested to support

the proposition that an increase in nigrostriatal dopamine activity underlies the effect of positive mood on creativity. As EBR has been suggested to reflect both changes in mesocorticolimbic and nigrostriatal activity (Elsworth et al., 1991), an exploratory approach was taken to examine these relationships in the present study. Although no significant relationships were observed between changes in EBR and changes in creativity, there was some evidence of a pattern towards a negative relationship for divergent thinking task performance (and to some degree convergent thinking performance). This suggests that increases in EBR may have been associated with decreases in performance on both of these creativity tasks, which is not in line with hypotheses.

A negative relationship between changes in EBR and divergent thinking task performance is contrary to Chermahini and Hommel's (2012) findings of positive relationship between these variables. One explanation for this disparity may be due to differences in the mean EBR of samples, as this was found to be 26.30 per min in the present study, compared to 14.10 in the aforementioned study. Median EBR is not reported in this study, but visual examination of scatterplots suggests that this can be estimated to be approximately 20 blinks per min. As the mean EBR was over this median value in the present study, this positions the majority of the sample in the negative slope of a hypothetical inverted U-shape relationship with divergent thinking. Therefore, any increases in EBR following the mood induction may be associated with a decrease in divergent thinking, whilst any decreases in EBR may have been associated with an increase in performance.

The fact that the sample in the present study had a greater mean EBR compared to the sample in the study conducted by Chermahini and Hommel (2012), may also explain why these authors' findings of an inverted U-shaped relationship between pre-induction EBR and divergent thinking performance was not replicated. As participants in the present study had a higher EBR, they would be situated in the negative slope of the inverted U-shape. Therefore, this would produce a negative linear relationship between pre-induction EBR and divergent thinking performance when examined. Although a negative linear relationship did not approach significance in analyses, a slight negative linear trend was still apparent in the scatterplot (Figure 3.6). Therefore, this supports the suggestion that the relationship between EBR and divergent thinking may be dependent upon the particular characteristics of the sample.

Chermahini and Hommel (2012) found that baseline EBR moderated the influence of positive mood on divergent thinking. In the present study, it was hypothesised that positive mood low in appetitive motivation would result in enhanced divergent thinking for those individuals with

a lower EBR. However, EBR was not found to moderate the influence of positive mood on divergent thinking, but instead moderate the influence of positive mood on convergent thinking. This was such that positive mood high in appetitive motivation resulted in enhanced performance, but only for those individuals with a lower EBR. This result does not fit with the observed finding that there was no quadratic relationship between EBR and convergent thinking, or the finding of an overall negative linear relationship between change in EBR and convergent thinking performance across the sample. Furthermore, this finding is even more surprising considering the lack of changes in positive mood or EBR observed following the mood induction.

3.5.6. Conclusions

The present study aimed to examine the moderating role of appetitive motivation, in relation to the influence of positive mood on creativity. However, positive mood inductions that were high and low in appetitive motivation did not result in the expected changes in positive affect, which was likely due to a combination of methodological factors. Therefore, it was unsurprising that neither mood induction was found to influence creativity, and that there were no correlations between changes in positive affect and creativity. However, there was some evidence of a negative relationship between activated positive affect and divergent thinking at the post-induction timepoint, which is in line with an antagonistic relationship between control processes (i.e., increased activated positive affect is beneficial for narrower/more stable cognition, but detrimental for broader/more flexible cognition) (Goschke, 2000). However, a negative relationship was also observed between activated positive affect and convergent thinking. Although, this may have been due to the fact that the Remote Associates Test requires an element of divergent thinking.

The second aim of the present study was to examine neurobiological mechanisms that may underlie the influence of positive mood on creativity. No differences in EBR were found between the high and low appetitive conditions following the mood inductions, which was likely due to the ineffectiveness of this procedure. However, a general pattern towards a negative relationship between EBR and activated positive affect was observed at the pre-induction timepoint, which may reflect the proposed reciprocal relationship between nigrostriatal and mesocorticolimbic systems (Cools & D'Esposito, 2011). However, a similar pattern was found for EBR and deactivated positive affect, which may have been due to the use of the UMACL, as this does not provide an accurate measure of deactivated positive affect.

In addition, previous findings of an inverted U-shaped relationship between baseline EBR and divergent thinking, and a negative trend for convergent thinking (Chermahini & Hommel, 2010) were not replicated in the present study.

The previously demonstrated correlation between increases in EBR and increases in divergent thinking (Chermahini & Hommel, 2012) was also not replicated. Instead, there was a trend towards increases in EBR being associated with decreases in divergent thinking (also the case for convergent thinking, but further from significance). This may be due to a higher mean EBR for the sample compared to previous research (i.e., Chermahini & Hommel, 2012), situating participants towards the negative slope of a possible inverted U-shape at baseline. Previous findings that baseline EBR moderated the influence of positive mood on divergent thinking (Chermahini & Hommel, 2012), were also not replicated. However, baseline EBR was found to moderate the influence of positive mood on convergent thinking, such that performance was enhanced in the high appetitive condition, but only for those with a lower pre-induction EBR. An explanation for this finding is unclear, as this mood induction was assumed not to be effective, and a quadratic relationship between pre-induction EBR and convergent thinking was not observed.

4. Study 2 – Appetitive motivation moderates the effect of positive mood on divergent thinking and spontaneous eye blink rate

4.1. Abstract

Study 1 examined whether the effect of positive mood on divergent and convergent thinking was dependent on appetitive motivation, based on the motivational intensity model (Gable & Harmon-Jones, 2010). Additional aims were to examine the effect of mood inductions on EBR, and the relationships between EBR and divergent and convergent thinking. This was based on the proposition that dopamine activity may underlie the influence of positive mood on cognition (Ashby et al., 1999). However, mood inductions were not found to be effective in Study 1, and were also found to have no effect on divergent/convergent thinking or EBR. This may have been due to methodological issues, which potentially reduced participants' engagement with the experiment. Therefore, Study 2 used a modified design to re-examine the aims of Study 1 (only in relation to divergent thinking)

Thirty-two participants completed a laboratory-based experimental study and were randomly assigned to a high or low mood condition. Participants completed a neutral and a positive mood induction in separate experimental sessions. Inductions involved the same stimuli as Study 1, but participants were alone and used headphones to listen to music, and EBR was assessed during this period using electrooculography. Positive affect was measured using the 12-Point Affect Circumplex Scale (12-PACS; Yik, Russell, & Steiger, 2011) at pre- and post-induction timepoints. Following the post-induction 12-PACS assessment, participants completed the Alternate Uses Task (Guilford, 1967) to assess divergent thinking.

ANOVAs demonstrated that mood inductions were effective, and that appetitive motivation moderated the effect of positive mood on divergent thinking – performance was enhanced for the low appetitive, but attenuated for the high appetitive induction (i.e., in line with the motivational intensity model). However, the opposite effect was demonstrated for EBR, suggesting a decrease in dopamine for low appetitive positive mood may attenuate divergent thinking, whilst an increase for high appetitive positive mood may be enhance divergent thinking. Regression analysis demonstrated a non-significant negative relationship between EBR in the neutral induction and divergent thinking. This is in line with Study 1 and suggests a negative relationship between dopamine activity and divergent thinking at baseline.

4.2. Introduction

Study 1 aimed to examine the moderating role of appetitive motivation in relation to the influence of positive mood on creativity, as well as in relation EBR – a physiological indicator of dopamine activity. However, the mood induction did not result in the expected changes in positive affect, allowing only reliable conclusions to be drawn regarding the relationships between these variables in the absence of a mood induction. It was suggested that the mood induction may have been ineffective in part due to the complex nature of the experimental design. Participants completed divergent and convergent thinking tasks twice within one session (i.e., preceding and following a mood induction), which may have resulted in fatigue and a failure to engage with the mood induction. Therefore, the present study will aim to simplify the experimental design of Study 1, to examine the moderating role of appetitive motivation, using only one type of thinking process involved in creativity.

4.2.1. Positive Mood and Divergent Thinking

The focus of the present study is on divergent thinking. There are only a small number of studies that have examined the influence of positive mood on performance in convergent thinking tasks – the other type of creativity process examined in Study 1 (Estrada et al., 1994; Rowe et al., 2007). However, there has been a much greater focus on divergent thinking tasks (Chermahini & Hommel, 2012; R. S. Friedman et al., 2007; L. H. Phillips et al., 2002; Tan & Qu, 2014; Vosburg, 1998; Vulpe & Damoiu, 2011), which may be because divergent thinking is suggested to be the hallmark of creative thinking (Kenett et al., 2014). Therefore, findings relating to the effect of positive mood on this process (and the possible moderation by appetitive motivation) will be of greater theoretical relevance, and, as such, may have further reaching implications within the field of creativity research. Furthermore, a focus solely on divergent thinking also allows a more detailed examination of the influence of positive mood on this type of creativity.

Guilford (1967) described divergent thinking as generating ideas across different fields, to produce many possible solutions. Creative outcomes produced as a result of this process are suggested to have four characteristics: fluency, flexibility, originality, and elaboration. Fluency can be described as generating a large number of ideas or producing a number of different solutions to a problem. Flexibility involves producing a variety of ideas from different categories or drawing solutions from diverse domains. Originality refers to generating ideas that are novel or producing unique or unusual solutions to a problem. Elaboration can be

described as producing a large amount of detail for ideas, in terms of embellishing or developing and adding to detail to these. Therefore, focus on only divergent thinking in the present study will allow examination of the influence of positive mood on these four characteristics of divergent thinking.

The Alternate Uses Task was developed by Guilford (1967) to assess the four divergent thinking characteristics. This task requires participants to produce as many uses as possible for a household object, within a limited period of time. The total number of ideas produced provides a measure of fluency, flexibility is measured as the number of ideas generated from different categories of idea, whilst the uniqueness of ideas provides a measure of originality, and elaboration is measured as the amount of detail provided for each idea. Using this measure, the relationship between self-reported positive mood (i.e., in the absence of a mood induction) and performance on the Alternate Uses Task was examined by Vosburg (1998). It was found that greater self-reported positive mood was associated with enhanced divergent thinking performance, in terms of resulting in greater flexibility, fluency, and originality on this task – although the latter was only a trend.

Other studies have examined the influence of positive mood inductions on the characteristics of divergent thinking on the Alternate Uses Task. Two of these studies found that fluency was greater as a result of positive mood inductions (R. S. Friedman et al., 2007; L. H. Phillips et al., 2002), whilst another study found that this resulted in an increase in flexibility (Chermahini & Hommel, 2012). However, Tan and Qu (2014) found greater fluency and flexibility following a positive mood induction, whilst Vulpe and Damoiu (2011) found that this resulted in greater fluency and flexibility, as well as a trend towards greater originality. These studies suggest that positive mood results in enhanced divergent thinking, but that this effect may vary dependent on the characteristics examined. Although, it is important to note that it is not clear whether these studies examined all of the characteristics for divergent thinking and only reported significant effects, or whether only these characteristics were examined.

4.2.2. Issues with Design

An issue with the experimental design of Study 1 was the need to create a baseline condition for comparison. This meant that measures were completed twice: preceding and following a positive mood induction, which may have contributed to fatigue for the participants. Therefore, rather than comparing to a baseline condition, the present study will compare measures between positive and neutral mood induction conditions – completed in separate experimental

sessions. The mood induction procedure will be the same in both sessions, with the only difference being the type of mood induced. Therefore, it is possible to compare EBR that is recorded during the mood induction period, as opposed to afterwards. In addition, participants in Study 1 may have also felt self-conscious, as EBR was measured by filming participants throughout the experimental period, which could have reduced engagement with the mood induction. As a result, EBR will be recorded using electrooculogram (EOG) in the present study.

Some changes will also be made to the mood induction procedure in the present study compared to Study 1, based on published guidelines for computerised mood inductions (O. J. Robinson et al., 2012). These changes include the researcher leaving the participant alone in the laboratory during the mood induction period, and the participant listening to the music through headphones, which is proposed to help the participant to engage in the mood induction task. Furthermore, Study 1 assessed changes in mood using the UMACL, which measures mood using a 4-point Likert scale. However, it is suggested that the most effective way to assess changes in mood as a result of laboratory based mood inductions is to use a visual analogue scale (O. J. Robinson et al., 2012). This provides a more sensitive measure of subtle changes in mood, compared to those using categorical response scales, such as the UMACL (Waltz, Strickland, & Lenz, 2005).

In addition, the UMACL measures positive affect using two factors – Hedonic Tone and Energetic Arousal. Hedonic Tone measures valence and was used as a measure of deactivated positive affect in Study 1, whilst Energetic Arousal measures activation of a positive valence, and was used as a measure of activated positive affect. However, using the Hedonic Tone factor does not take into account the level of activation experienced during deactivated positive affect. Therefore, this may have not allowed deactivated positive affect to be measured accurately in the previous study. As a result, the present study will use a more recently developed measure – the 12-Point Affect Scale 12-PACS (Yik et al., 2011), which allows positive affect to be measured using factors that take into account both valence and activation. In combination with a visual analogue response scale, this should provide a more accurate measure of mood in the present study.

4.2.3. Present Study

The first aim is to examine whether appetitive motivation moderates the influence of positive mood on divergent thinking, by reprising the experimental design from Study 1. To address

this, performance on a divergent thinking task will be examined after participants complete a positive mood induction (either high or low in appetitive motivation) and compared to performance following a neutral mood induction. In line with the predictions of Study 1, it is hypothesised that only positive mood that is low in appetitive motivation will enhance divergent thinking performance. This is based on the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect low in appetitive motivation results in broader/more flexible cognition, whilst narrower/more stable cognition occurs for positive affect high in appetitive motivation. Therefore, it is also hypothesised that positive mood high in appetitive motivation will have no effect on divergent thinking performance (or a possible negative trend), which is based on the suggestion that cognitive control relies on an antagonistic balance between flexibility and stability (Goschke, 2000).

Focus only on divergent thinking in the present study (as opposed to both divergent and convergent thinking in Study 1), allows a more in-depth examination of the influence of positive mood on divergent thinking characteristics. However, it is difficult to identify the possible characteristics that may be targeted by positive mood, although flexibility may be the most obvious target. This is based on the neuropsychological theory of positive affect (Ashby et al., 1999), which suggests that positive affect enhances divergent thinking by facilitating the activation of non-dominant sets and the ability to overcome dominant sets. Therefore, it may seem likely that flexibility (i.e., the production of ideas from a variety of different categories) may be enhanced by positive mood. However, studies have demonstrated that positive mood also effects fluency (e.g., L. Phillips et al., 2002), and possibly originality (Vulpe & Damoiu, 2011). Therefore, an exploratory approach will be taken to examine the influence of positive mood on specific divergent thinking characteristics.

The second aim of the present study is to explore the possible mechanisms underlying the influence of positive mood on divergent thinking, using indirect measures of dopamine activity. To address this, EBR during positive mood inductions (i.e., those high and low in appetitive motivation) will be compared to EBR during a neutral mood induction. Chermahini and Hommel (2012) demonstrated that a positive mood induction (which was presumably low in appetitive motivation) resulted in an increase in EBR, and this was suggested to reflect an increase in nigrostriatal dopamine activity. However, pharmacological manipulations that increase dopamine activity primarily in the nigrostriatal and mesocorticolimbic pathways have both been demonstrated to result in an increase in EBR (Elsworth et al., 1991). Depue and Collins (1999) suggest that positive affect that is high in appetitive motivation results in an

increase dopamine activity in the mesocorticolimbic system. Therefore, the present study takes an exploratory approach to examine the effect of positive mood inductions that are high and low in appetitive motivation on EBR.

Chermahini and Hommel (2012) also demonstrated that, in the absence of a mood induction (i.e., at baseline), EBR and divergent thinking were related in a quadratic inverted-U-shape. Therefore, the relationship between these variables will be examined in the present study. Although the effect of pharmacological manipulations targeting dopamine activity in the mesocorticolimbic and nigrostriatal pathways have both been found to increase EBR (Elsworth et al., 1991), it is suggested that EBR assessed at baseline primarily reflects dopamine activity of the nigrostriatal pathway (Jongkees & Colzato, 2016). Therefore, it is expected that Chermahini and Hommel's (2012) findings will be replicated, and it is hypothesised that, for the neutral induction (i.e., at baseline), EBR will be related to divergent thinking performance in a quadratic inverted U-shaped relationship. This is despite the fact that this relationship was not observed in Study 1, as this may have been due to issues with the methodological design of the study.

Chermahini and Hommel (2012) also demonstrated that increases in EBR following their positive mood induction were associated with increases in divergent thinking. To examine this in the present study, correlations will be examined between EBR and divergent thinking performance for the positive mood induction. It is hypothesised that for the positive induction, EBR will be positively related to divergent thinking task performance. Furthermore, in line with the U-shaped relationship between baseline EBR and divergent thinking, Chermahini and Hommel (2012) also found that the effect of the positive mood induction on divergent thinking performance was moderated by baseline EBR. In the present study, it is hypothesised that divergent thinking performance will be increased as a result of the low appetitive positive mood induction, but only for those with a lower EBR during the neutral induction. This would be in line with the pattern of results that were demonstrated by Chermahini and Hommel (2012), although this study did not take into account the motivational intensity of positive mood induced.

4.2.4. Aims and Hypotheses

1. To examine whether appetitive motivation moderates the influence of positive mood on divergent thinking, by reprising the experimental design from Study 1.

i) It is hypothesised that only positive mood that is low in appetitive motivation will enhance divergent thinking performance, whilst positive mood high in appetitive motivation will have no effect on divergent thinking performance (or a possible negative trend).

ii) An exploratory approach will be taken to examine the influence of positive mood on specific divergent thinking characteristics.

2. To explore the possible neurobiological mechanisms underlying the influence of positive mood on divergent thinking, using indirect physiological measures of dopamine activity (i.e., EBR).

i) An exploratory approach to examine the effect of positive mood inductions that are high and low in appetitive motivation on EBR.

ii) It is hypothesised that for the neutral induction (i.e., at baseline), EBR will be related to divergent thinking performance in a quadratic inverted U-shaped relationship.

iii) It is hypothesised that for the positive induction, EBR will be positively related to divergent thinking task performance.

iv) It is hypothesised that divergent thinking performance will be increased as a result of the low appetitive positive mood, but only for those with a lower EBR during the neutral induction.

4.3. Method

4.3.1. Participants

Thirty-two participants were recruited, which is in line with previous studies (cf. Chermahini & Hommel, 2010). There were 21 (65.60%) female and 11 (34.40%) male participants, with an age range of 18-64 years (M = 41.91 years, SD = 15.26). Participants were recruited using advertisements around a London university and received £10 in compensation for their time. Participants were randomly assigned to one of the two mood induction conditions: positive affect high in appetitive motivation (n = 16), and positive affect low in appetitive motivation (n = 16). The study was approved by the University Research Ethics Committee, and all participants provided informed consent at the start of the study, and were fully debriefed at the end of the study.

4.3.2. Measures

4.3.2.1. Mood Induction

The vignettes and music used for the positive mood inductions were the same as in Study 1, but new vignettes and music were used for a neutral mood induction. The vignettes selected for the neutral condition were "*You are shopping at the supermarket for groceries that you need to purchase for your dinner*" and "*You are driving down a long stretch of road as you make your way to work in the morning*". The music selected for this condition was "*The Largo Movement*" from "*The New World Symphony*" by Dvorak. These were adapted from other mood induction studies (Larsen & Ketelaar, 1989; Mayer et al., 1995; Smillie et al., 2012). Unlike Study 1, participants listened to music through headphones and were alone in the testing room during the mood induction period.

4.3.2.2. Positive Affect

An adapted version of the 12-Point Affect Circumplex Scale (12-PACS; Yik et al., 2011) was used to measure positive affect. This scale is based on a circumplex model of affect that incorporates core affect from earlier two and four dimensional models (Russell, 1980; Thayer, 1989; Watson & Tellegen, 1985), in order to form a more complex six dimensional model of affect. This model can be described as a circle, with a vertical axis representing a Pleasure dimension, and a horizontal axis representing an Activation dimension. This forms four basic quadrants of affect, which each constitute 45° of the circle. These are in line with previous two dimensional models and are referred to as Activated Pleasure, Deactivated Pleasure, Activated Displeasure, and Deactivated Displeasure. However, a further four dimensions are added to the model, splitting each quadrant into three segments. This gives a total of twelve segments overall, with each segment constituting 30° of the circle. Each segment differs in degrees of pleasure and activation, and affective states may be described as fitting into one of these segments, based upon their affective properties. The present study will focus only on the Activation-Pleasure and Deactivation-Pleasure quadrants of the circumplex, which together constitute 180° of the circle.

The Activation-Pleasure quadrant is separated into segments of Activation at 0°, Pleasant Activation at 30°, Activated Pleasure at 60°, and Pleasure at 90°. The Deactivation-Pleasure quadrant shares the segment of Pleasure at 90°, Deactivated Pleasure at 120°, Pleasant

Deactivation at 150°, and Deactivation at 180°. The 12-PACS has one item to represent each segment, therefore scores on Pleasant Activation and Activated Pleasure items will be collapsed to form an Activated Positive Affect factor, whilst scores on Pleasant Deactivation and Deactivated Pleasure items will be collapsed to form a Deactivated Positive Affect factor. There are three response formats to assess affect in relation to each segment: 1) using adjectives, such as '*aroused*' and '*excited*', for which participants must respond on a scale from 1 (*not at all*) to 5 (*extremely*); 2) using statements such as '*I was happy*' and '*I was feeling elated*', for which participants must respond on a scale from 1 (*strongly disagree*) to 5 (*strongly agree*); and 3) using phrases, such as '*I felt elated*' and '*I felt inspired*', for which participants must respond on a scale from 1 (*not at all*) to 4 (*very well*), to indicate how well they believe the scale describes them. However, the authors propose this can be reduced to a one response format to save time. Therefore, the adjective format was used in the current study, and adapted for participants to rate their present mood.

Based on recent work demonstrating that mood induction procedures may be best able to produce change measured on visual analogue scales (O. J. Robinson et al., 2012), the 12-PACS was adapted so that participants responded to the adjectives on a 100mm visual analogue scale, from '*not at all*' to '*extremely*'.

Two versions of the 12-PACS were used, with participants completing one version before, and one version after the mood induction. Previous research has demonstrated reliability and validity of this scale based on other dimensional models and related personality constructs (Yik et al., 2011). Internal consistency for Activated and Deactivated Positive Affect factors was demonstrated to be good in the present study ($\alpha \geq .79$).

4.3.2.3. EBR

Vertical electrooculogram (EOG) recording was used to assess EBR as a physiological marker of dopamine activity (Karson, 1983). Eye blinks are detected by examining voltage differences between electrodes placed above and below the eye[2]. Electrodes were placed approximately 3 cm above and 2 cm below the left eye, as measured from the centre of the pupil, with a ground

[2] The eye acts as an electrical dipole between the positive potential of the cornea and the negative potential of the retina, oriented along the line of sight, therefore an electrode placed in the vicinity of the eye becomes more positive when the eye rotates towards it and less positive when it rotates in the opposite direction (Heide, Koenig, Trillenberg, Kömpf, & Zee, 1999).

electrode placed in the centre of the forehead, and a reference on the left ear (Barbato et al., 2000).

EOG signals were recorded using a 19-channel Mitsar-EEG-201 system with a sampling rate of 500 Hz, and WinEEG v2.103.70 was used to analyse data offline. In line with previous studies, a 0.5-15 Hz band pass filter was applied, and eye blinks were visually determined based on sharp increases in the amplitude of the waveform (greater than 100 μV) occurring for less than 500 ms (Byrne, Norris, & Worthy, 2015; Nakanishi, Mitsukura, Wang, Wang, & Jung, 2012). Increases in the amplitude of the waveform were not counted as eye blinks when consistent with horizontal eye movements (Barbato, Della Monica, Costanzo, & De Padova, 2012).

EBR was measured throughout the mood induction period, with the first minute considered to be a period of adaptation and not included in analysis (Borges et al., 2010). Therefore, eye blink frequency was counted in the following 4min, which were divided into 4 x 60sec periods, allowing the mean number of eye blinks per minute to be calculated (Dreisbach et al., 2005). In line with previous studies, registration always occurred during daylight hours, based on findings that EBR is stable during the day (Barbato et al., 2000). Inter-reliability for the determination of eye blinks from EOG recordings was found to be good, for a randomly selected 10% sample of the data across induction and mood conditions (r = .92, p = .002).

4.3.2.4. Divergent Thinking

As was the case in Study 1, two versions of the Alternate Uses Task (Guilford, 1967) were used to measure divergent thinking. However, in the current study, participants were given only a single object (*cup* or *pencil*), and had 5min to produce as many uses for this object as possible (cf. Chermahini & Hommel, 2010).

Scores were calculated for the flexibility component of divergent thinking following the same procedure as Study 1. In addition, scores were also calculated for fluency, elaboration, and originality. Fluency was calculated as the total number of responses provided. Elaboration is the amount of detail provided for each response. For example, a response to use of a pencil as "a weapon" would score 0, whilst "a weapon to stab someone with if you are attacked" would score 2 (one point for detail about the type of injury inflicted, and one point for the context detail). Originality was calculated by comparing each response to those given by the rest of the responses from the sample. Responses that were given by less than 10% of the sample were

given a score of 1, and responses given by less than 5% of the sample were given a score of 2. Scores for elaboration and originality were divided by fluency, to prevent contamination from this component. Inter-rater reliability was found to be good for all divergent thinking characteristics, which were based on a randomly selected 10% sample of the data across mood inductions and conditions ($r = \geq .95$, $p \leq .001$).

4.3.3. Procedure

Participants were required to attend the laboratory for two sessions, scheduled one week apart at the same time of day. Before arriving for the first session, participants completed an online survey including demographic questions. Upon arrival at the laboratory, participants were seated and the researcher prepared the participant for EOG recording. Afterwards, participants completed a paper version of the 12-PACS, and had the opportunity to ask any questions before the researcher left the room. Next, participants completed the computerised mood induction, whilst EOG was recorded, followed by the second version of the 12-PACS. The Alternate Uses Task was then presented on the computer, whilst participants recorded their answers on paper. After 5min, a beep signalled the end of the experiment, and the researcher re-entered the room.

The same procedure was followed in both sessions, with the only difference being the mood induction condition. In one session participants would complete a positive mood induction and in the other session they would complete the neutral mood induction. The order of mood induction conditions was counterbalanced across participants, as was the order of the Alternate Uses Task versions, and the 12-PACS versions, which were counterbalanced within mood induction conditions. Participants received £10 for their time at the end of the second session of the study. Computerised tasks were presented and timed using Matlab R2014, and the total time for participation in each session was approximately 30 min.

4.4. Results

4.4.1. Data Screening

One participant's data for EBR could not be included due to a technical error with EOG recording. One further participant's data was excluded, due to a medical issue that may have affected visual sensitivity (Barbato et al., 2000). Other data screening techniques followed the procedures outlined in the previous chapter.

There were no outliers (i.e., values that were 1.5 interquartile ranges from the median or with a z-score 3.29 standard deviations above the mean), other than one value for elaboration on the divergent thinking task in the high appetitive condition for the positive induction. This was winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall pattern or significance of results for these analyses.

Data was approximately normally distributed for the majority of variables, with some minor deviations in normality for elaboration and originality variables within mood condition and EBR cells. Transformations did not correct for this, but skewness and kurtosis statistics were within acceptable limits +/- 3 (George & Mallery, 2010) Therefore, this should not be problematic for ANOVA analysis, as simulation studies (e.g., Schmider, Ziegler, Danay, Beyer, & Buhner, 2010) have consistently demonstrated that ANOVA is generally robust against moderate deviations from normality, even with small sample sizes.

Linear relationships were observed between all variables for which correlation analysis was performed. For regression analyses, data was determined to be homoscedastic, and variance of the residuals was determined to be constant. Residuals were also determined to be independent.

4.4.2. Mood Induction Check

To examine the effectiveness of the mood inductions, two separate 2 (mood condition: high vs. low appetitive) by 2 (induction: positive/neutral) by 2 (time: pre-induction/post-induction) mixed ANOVAs were conducted with activated and deactivated positive affect.

4.4.2.1. Activated Positive Affect

The results of the ANOVA analysis for activated positive affect is displayed in Table 4.1. This table demonstrates that there was a significant main effect for induction, as well as significant interaction effect for induction by mood condition, and a time by mood condition. Other main and interaction effects were not significant ($p \geq .158$). However, the pertinent induction by time by mood condition interaction was significant.

Table 4.1. *ANOVA results for differences in activated positive affect depending on induction, time, and mood condition.*

Effect	df	*F*	*P*	η^2_p
Induction	1, 30	16.31	< .001	0.35
Time	1, 30	3.00	.158	0.07
Mood Condition	1, 30	1.39	.248	0.04
Induction by Time	1, 30	1.63	.211	0.05
Induction by Mood Condition	1, 30	14.90	.001	0.33
Time by Mood Condition	1, 30	7.38	.011	0.20
Induction by Time by Mood Condition	1, 30	10.25	.003	0.26

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in activated positive affect within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons ($\alpha = .013$). The means for this analysis are displayed in Figure 4.1.

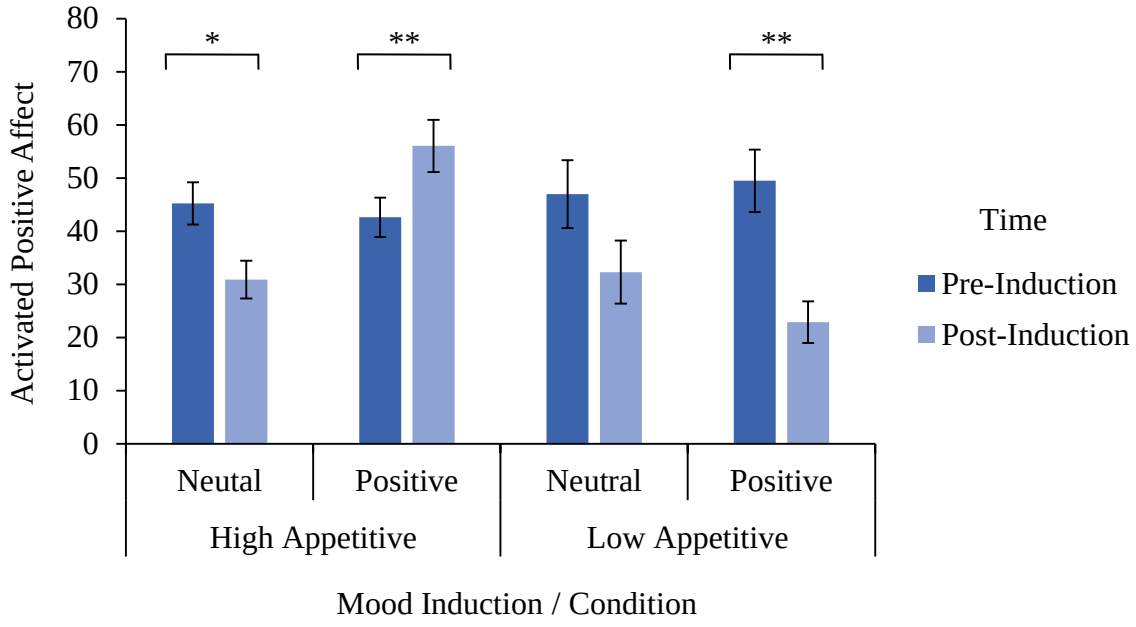


Figure 4.1. *Activated positive affect at different time points for each mood induction and condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons * p < .013, ** p < .003.*

For the high appetitive condition, Figure 4.1 demonstrates that there was a significance increase in activated positive affect for the positive induction [$t(15) = 2.61$, $p = .010$, $d = 0.77$], [($M = 42.63$, $SD = 14.81$) to ($M = 56.06$, $SD = 19.59$)]. There was also a significant decrease in activated positive affect for the neutral induction [$t(15) = -4.03$, $p = .001$, $d = -0.98$].

For the low appetitive condition, Figure 4.1 demonstrates that there was a significant decrease in activated positive affect for the positive induction [$t(15) = -3.54$, $p = .002$, $d = -0.77$], and a decrease also approached significance in the neutral condition [$t(15) = -2.45$, $p = .027$, $d = 0.77$]

This suggests that the mood induction was effective, in terms of resulting in an increase in activated positive affect only for the positive induction in the high appetitive mood condition.

4.4.2.2. Deactivated Positive Affect

The results of the ANOVA analysis for deactivated positive affect is displayed in Table 4.2. This table demonstrates that there was a significant main effect for mood condition, as well as significant interaction effect for time by mood condition. Other main and interaction effects were not significant ($p \geq .105$). However, the pertinent induction by time by mood condition interaction was significant.

Table 4.2. *ANOVA results for differences in deactivated positive affect depending on induction, time, and mood condition.*

Effect	df	*F*	*p*	η^2_p
Induction	1, 30	0.01	.925	0.00
Time	1, 30	0.46	.504	0.02
Mood Condition	1, 30	11.34	.002	0.27
Induction by Time	1, 30	0.76	.392	0.03
Induction by Mood Condition	1, 30	2.79	.105	0.09
Time by Mood Condition	1, 30	5.19	.030	0.15
Induction by Time by Mood Condition	1, 30	12.02	.002	0.29

Planned contrasts using simple effects analysis with paired t-tests were conducted to examine changes in deactivated positive affect within mood conditions (Bonferroni corrected $\alpha = .013$). The means for this analysis are displayed in Figure 4.2.

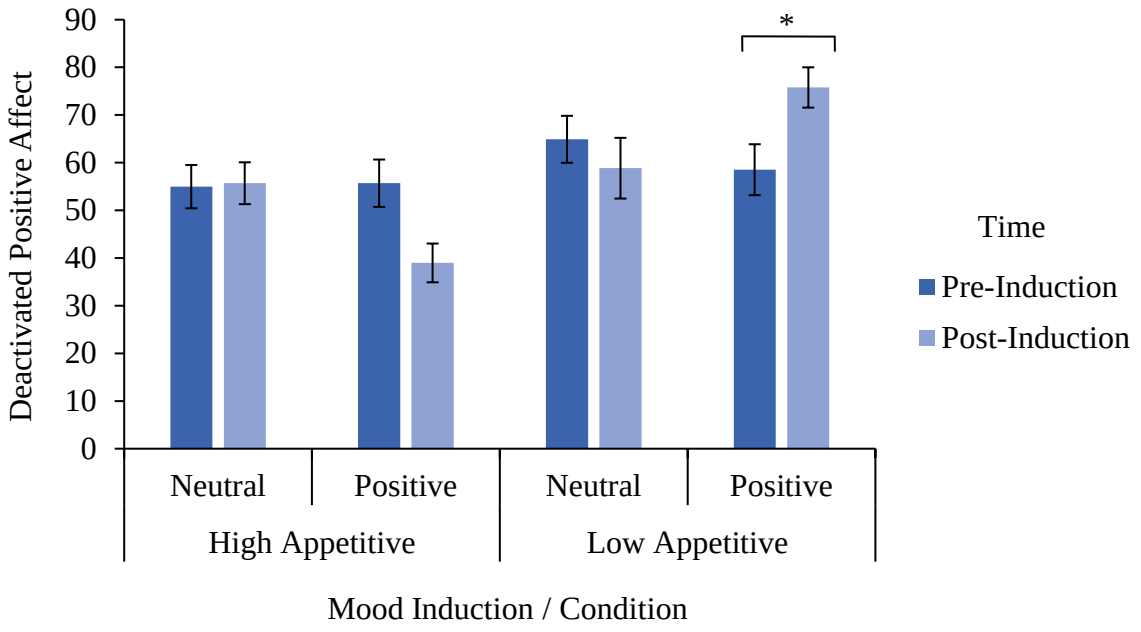


Figure 4.2. *Deactivated positive affect at different time points for each mood induction and condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons * $p < .013$, ** $p < .003$.*

For the low appetitive condition, there was a significant increase in deactivated positive affect for the positive induction [$t(15) = 2.76$, $p = .008$, $d = 0.89$], [($M = 58.53$, $SD = 21.38$) to ($M = 75.78$, $SD = 16.91$)]. However, there was no significant difference in deactivated positive affect for the neutral induction [$t(15) = -0.78$, $p = .223$, $d = -0.27$].

For the high appetitive condition, a decrease in deactivated positive affect for the positive induction approached significance [$t(15) = -2.38$, $p = .015$, $d = -0.99$], whilst there was no significant difference for the neutral induction [$t(15) = 0.13$, $p = .895$, $d = 0.04$].

Therefore, the mood induction was effective, in terms of resulting in an increase in deactivated positive affect following only the positive mood induction for the low appetitive condition.

4.4.3. Effect of Mood on Divergent Thinking

To examine the influence of mood on divergent thinking performance, four separate 2 (induction: positive/neutral) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVAs were conducted with flexibility, fluency, originality, and elaboration scores for the divergent thinking task. Levene's test for homogeneity of variance was significant for flexibility (positive induction) and fluency (neutral induction), suggesting that there may not

be equal variances between mood condition groups. However, this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups when cell sizes are equal (Zimmerman, 2004).

Table 4.3 summarises the result of ANOVA analysis for flexibility. Main effects were not significant (*p*'s ≥ .776), but the pertinent induction by mood condition interaction effect was significant.

Table 4.3. *ANOVA results for differences in flexibility in divergent thinking performance dependant on induction and mood condition.*

Effect	df	*F*	*p*	η^2_p
Induction	1, 30	0.83	.776	0.00
Mood Condition	1, 30	0.04	.851	0.00
Induction by Mood Condition	1, 30	12.59	.001	0.30

Planned contrasts (using simple effects analysis) were conducted with paired t-tests to examine differences in flexibility within the mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to two multiple comparisons (α = .025). Figure 4.3 displays the means for this analysis.

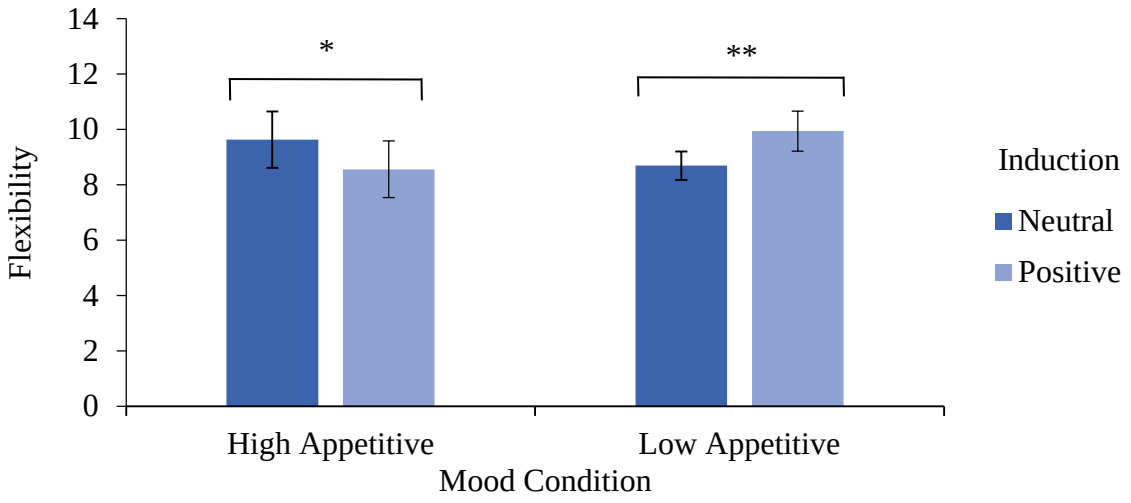


Figure 4.3. *Flexibility scores on the divergent thinking task for different inductions within mood conditions. Error bars reflect one standard error above and below the mean. Bonferroni correction for two multiple comparisons * p < .025, ** p < .005.*

Figure 4.3 shows that, for the low appetitive condition, there was significantly greater flexibility [$t(16) = 2.33$, $p = .005$, $d = 0.50$], for the positive induction ($M = 10.00$, $SD = 2.07$) compared to the neutral induction ($M = 8.50$, $SD = 2.76$). This is in line with findings of Chermahini and Hommel (2010), who found significantly greater flexibility as a result of a positive mood induction, which was presumably low in appetitive motivation.

However, Figure 4.3 also demonstrates that for the high appetitive condition, there was significantly lower flexibility, [$t(16) = -2.87$, $p = .006$, $d = -0.26$], for the positive induction ($M = 8.56$, $SD = 4.11$) compared to the neutral induction ($M = 9.56$, $SD = 3.97$). This suggests that appetitive motivation did in fact moderate the influence of positive mood on divergent thinking performance, such that flexibility was increased in the low appetitive condition, but reduced for the high appetitive condition.

Table 4.4 displays the ANOVA results for the other characteristics of divergent thinking. This demonstrates that there were no significant main or interaction effects for these characterises (F's ≤ 1.17, p's $\geq .278$), including the pertinent induction by mood condition interaction, suggesting no effects of positive mood on fluency, elaboration, or originality, even when taking into account appetitive motivation.

Table 4.4. *ANOVA results for differences in fluency, elaboration, and originality in divergent thinking performance depending on induction and mood condition.*

Effect	df	*F*	*p*	η^2_p
Fluency				
Induction	1, 30	0.08	.778	0.00
Mood Condition	1, 30	0.03	.857	0.00
Induction by Mood Condition	1, 30	1.17	.288	0.04
Elaboration				
Induction	1, 30	0.08	.778	0.00
Mood Condition	1, 30	0.03	.857	0.00
Induction by Mood Condition	1, 30	1.17	.288	0.04
Originality				
Induction	1, 30	0.08	.778	0.00
Mood Condition	1, 30	0.03	.857	0.00
Induction by Mood Condition	1, 30	1.17	.288	0.04

The means for the characteristics of divergent thinking within different inductions and mood conditions can be seen in Table 4.5.

Table 4.5. *Means (standard deviations) for fluency, elaboration, and originality in divergent thinking performance depending on induction and mood condition.*

	High Appetitive		Low Appetitive	
	Neutral	Positive	Neutral	Positive
Fluency	11.44 (4.55)	10.69 (4.55)	10.56 (4.55)	11.00 (4.71)
Elaboration	0.47 (0.37)	0.52 (0.28)	0.49 (0.37)	0.42 (0.28)
Originality	1.03 (0.84)	1.12 (0.95)	1.09 (0.84)	1.18 (0.95)

4.4.3.1. Relationships between Positive Affect and Divergent Thinking

Relationships between (post-induction) positive affect and divergent thinking task performance were explored using correlation analysis. These correlations are displayed in Table 4.6 and Table 4.7.

Table 4.6. *Correlations between divergent thinking characteristics and deactivated positive affect for neutral and positive inductions*

	Neutral		Positive	
	r	*p*	*r*	*p*
Flexibility	.31	.080	.03	.856
Fluency	.26	.160	-.06	.732
Elaboration	-.15	.416	-.19	.296
Originality	.01	.944	.21	.258

For deactivated positive affect, Table 4.6 demonstrates that there were slight non-significant trends towards weak positive correlations with flexibility, as well as fluency, following the neutral induction (r's $\geq .26$, p's $\leq .160$).

This provides some tentative evidence that divergent thinking performance may be positively related to deactivated positive affect, specifically in terms of flexibility and fluency. This is in line with Chermahini and Hommel's (2012) finding that change in positive affect following a positive mood induction (presumably inducing positive mood that was low in appetitive motivation) was positively associated with change in flexibility.

Table 4.7. *Correlations between divergent thinking characteristics and activated positive affect for neutral and positive inductions.*

	Neutral		Positive	
	r	*p*	*r*	*p*
Flexibility	-.18	.332	-.03	.880
Fluency	.02	.928	.09	.612
Elaboration	.29	.112	.24	.178
Originality	-.21	.240	-.02	.898

For activated positive affect, Table 4.7 demonstrates that there were no significant correlations, other than for a slight trend for a weak positive correlation with elaboration for both the neutral and positive inductions (*r*'s $\geq$ .24, *p*'s $\leq$ .178).

4.4.4. Effect of Mood on EBR

To examine the influence of mood on EBR, a 2 (induction: positive/neutral) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVA was conducted with EBR. The results of this analysis are summarised in Table 4.8.

Table 4.8. *ANOVA results for differences in EBR depending on induction and mood condition.*

Effect	df	*F*	*p*	η^2_p
Induction	1, 28	0.10	.758	0.00
Mood Condition	1, 28	0.23	.634	0.01
Induction by Mood Condition	1, 28	19.78	< .001	0.41

Table 4.8 demonstrates that there were no significant main effects (*p*'s $\geq$ .634), but that the pertinent induction by mood condition interaction was significant.

Planned contrasts using simple effects analysis were then conducted with independent and paired t-tests to examine differences in EBR between neutral and positive inductions for the mood conditions. A Bonferroni correction was used to correct for Type I error due to the two multiple comparisons (α = .025). Figure 4.4 displays the means for this analysis.

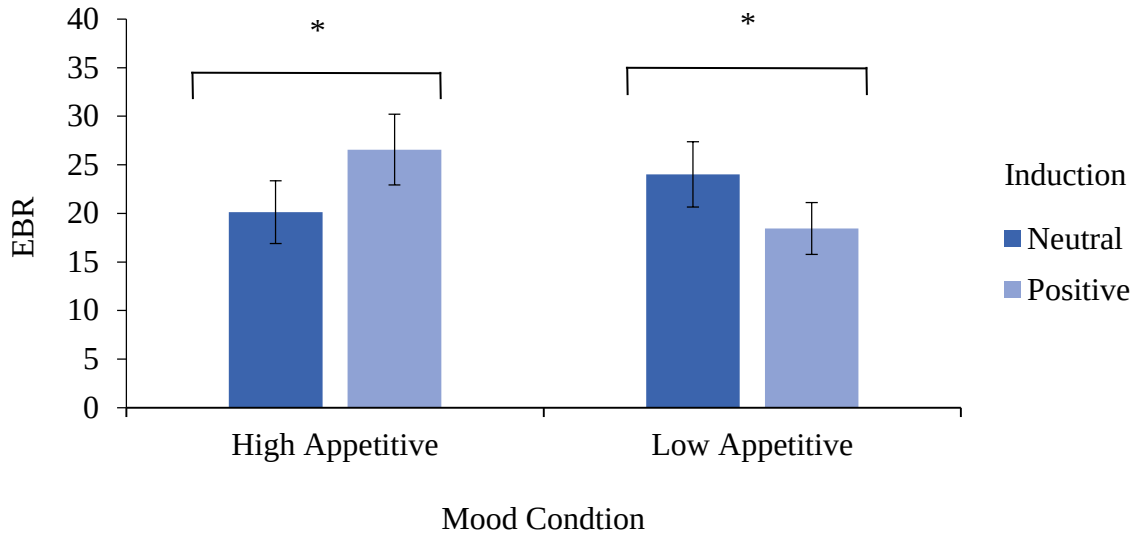


Figure 4.4. *EBR during different inductions within mood conditions. Error bars reflect one standard error above and below the mean. A Bonferroni correction was used to correct for inflated Type I error due to the two multiple comparisons * p < .025.*

For the low appetitive condition, Figure 4.4 shows that EBR was significantly reduced [$t(14) = -3.19$, $p = .004$, $d = -0.47$] during the positive induction ($M = 18.45$, $SD = 10.38$) compared to the neutral induction ($M = 24.03$, $SD = 13.00$). This is the opposite pattern of results compared to those found by Chermahini and Hommel (2012), as this study found that EBR was increased following a positive mood induction, which was presumably low in appetitive motivation.

For the high appetitive condition, Figure 4.4 shows that EBR was significantly increased [$t(14) = 3.13$, $p = .004$, $d = 0.48$] during the positive induction ($M = 26.57$, $SD = 14.10$) compared to the neutral induction ($M = 20.14$, $SD = 12.52$). This suggests that appetitive motivation moderated the effect of positive mood on EBR in the present study, such that this was decreased during the positive induction in the low appetitive condition, but increased during the high appetitive condition.

It is also worth noting that Figure 4.4 suggests that EBR during the neutral induction appeared higher in the low appetitive condition ($M = 24.03$, $SD = 13.00$) compared to the high appetitive condition ($M = 20.14$, $SD = 12.52$). However, when examined, this was far from significance ($p = .411$), suggesting that possible pre-existing differences in EBR between the mood conditions was unlikely to have influenced the effect of the positive inductions on EBR.

4.4.4.1. Relationships between Positive Affect and EBR

The relationships between positive affect (post-induction scores) and EBR were explored using correlation analysis.

For activated positive affect, there was no significant correlation with EBR for the neutral induction [$r(31) = -.01$ $p = .956$]. However, whilst there was a weak positive relationship for the positive induction, this did not approach significance [$r(31) = .23$ $p = .220$].

For deactivated positive affect, there were no significant correlations with EBR for the neutral induction [$r(31) = -.05$, $p = .780$] or for the positive induction [$r(31) = -.13$ $p = .508$].

This suggests that there were no relationships between positive affect and EBR, other than for a tentative positive relationship with activated positive affect.

4.4.5. Relationships between Neutral EBR and Divergent Thinking

To examine the fit for relationships between neutral EBR and divergent thinking during the neutral inductions, separate regression analyses were conducted with variables from the neutral induction for each divergent thinking characteristic. To avoid potentially problematic high multicollinearity with the quadratic term, the variables were centred prior to analysis (Aiken & West, 1991). The quadratic term was calculated by squaring the centred value for EBR. For all analyses, EBR was entered in the first step to test a linear fit, and the quadratic term was entered in the second step. Coefficients for this analysis are displayed in Table 4.9.

Table 4.9. *Coefficients for tests of linear and quadratic relationships between EBR and divergent thinking characteristics in the neutral induction.*

	Linear	Quadratic
	β	β
Flexibility	-.33	-.08
Fluency	-.30	-.08
Elaboration	-.31	-.13
Originality	-.01	.16

A linear model approached significance for EBR and flexibility [R^2= .11, F(1,30) = 3.52, p = .071], and adding the quadratic term did not significantly explain additional variance in the model [ΔR^2 = .00, F(2,30) = 1.78, p = .188]. A trend towards a negative linear relationship can be seen in Figure 4.5 which displays regression lines for this analysis. Therefore, this is not in line with the quadratic fit consistently demonstrated between EBR and flexibility in divergent thinking by Chermahini and Hommel (2010, 2012).

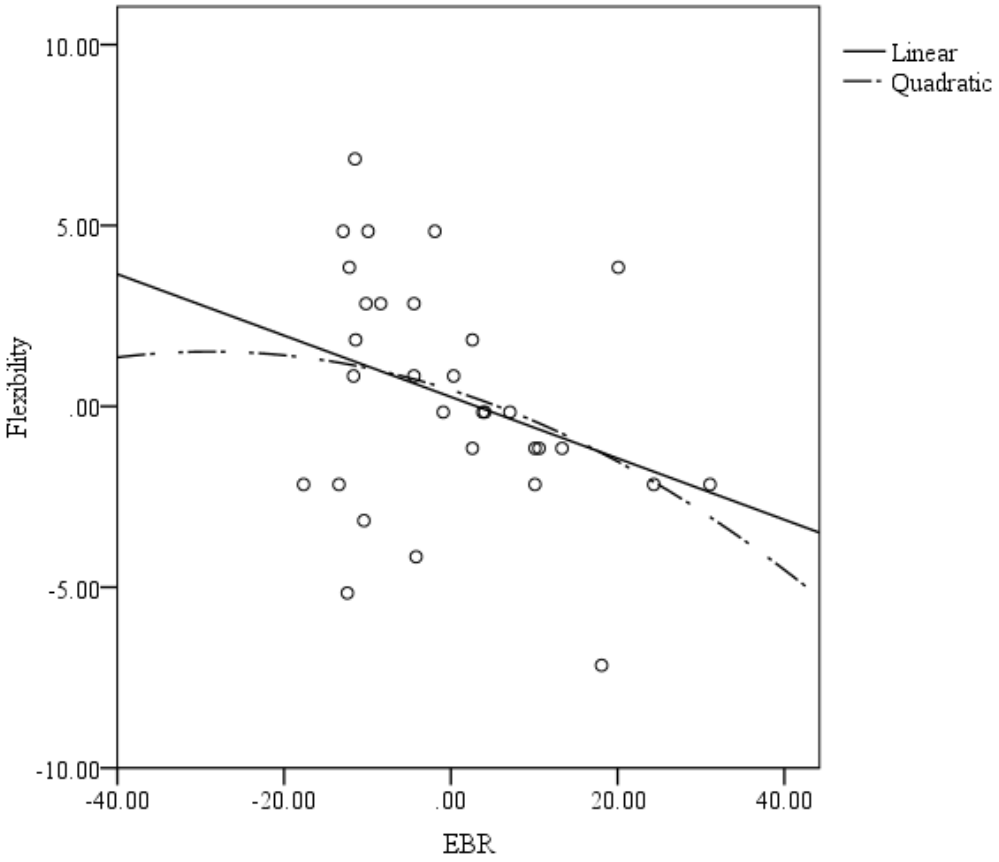


Figure 4.5. *Flexibility scores on the divergent thinking task as a function of EBR for the neutral induction.*

There was also a trend towards a negative linear model for fluency [R^2= .09, F(1,30) = 2.94, p = .097], and adding the quadratic term did not significantly explain additional variance [ΔR^2= .00, F(2,30) = 1.49, p = .243]. This was also the case for elaboration, as there was a trend towards a negative linear model [R^2= .10, F(1,30) = 3.15, p = .087], whilst the quadratic term was not found to explain additional variance in the model [ΔR^2= .01, F(2,30) = 1.73, p = .196]. Therefore, this is not in line with Chermahini and Hommel's (2010) findings of no significant relationships between EBR and fluency and elaboration characteristics of divergent thinking.

However, a linear model was found to be far from significance for originality [R^2= .00, F(1,30) = 0.00, p = .963], and adding the quadratic term did not significantly explain additional variance in this model [ΔR^2= .05, F(2,30) = 0.76, p = .472].

4.4.6. Moderating Effect of Neutral EBR on Positive Mood and Divergent Thinking

The lack of significant quadratic relationships between neutral EBR and divergent thinking performance observed in the previous section suggests that individual differences in EBR do not moderate the influence of positive mood on divergent thinking.

To confirm this, a median split was conducted on EBR in the neutral induction, forming a categorical variable with two levels suitable for this analysis. Separate 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) by 2 (EBR: higher/lower) mixed ANOVAs were conducted for flexibility, fluency, elaboration, and originality. Levene's test for homogeneity of variance was significant for flexibility and fluency (both neutral and positive inductions), but as previously stated, this should not be problematic for analysis.

Table 4.10 displays the ANOVA results for flexibility, and this table demonstrates that there were no significant main effects (F's $\leq$ 2.26, p's $\geq$ .144). The interaction effect for the induction by mood condition was significant, and means were in line with previous analysis (i.e., flexibility was increased following the positive induction for the low appetitive condition, but decreased for the high appetitive condition). However, all other interaction effects were not found to be significant (F's $\leq$ 0.67, p's $\geq$ .419), which included the pertinent mood by condition by EBR interaction.

Table 4.10. *ANOVA results for differences in flexibility in divergent thinking depending on induction, mood condition, and neutral EBR.*

Effect	df	F	p	η^2_p
Induction	1, 27	0.09	.762	0.00
Mood Condition	1, 27	0.26	.611	0.01
EBR	1, 27	2.26	.144	0.08
Induction by Mood Condition	1, 27	12.40	.002	0.32
Induction by EBR	1, 27	0.67	.419	0.02
Mood Condition by EBR	1, 27	0.10	.759	0.00
Induction by Mood Condition by EBR	1, 27	0.35	.557	0.01

The means for flexibility dependent on induction and EBR within each of the mood conditions are displayed in Figure 4.6 and are in line with a lack of interaction effect observed in analyses.

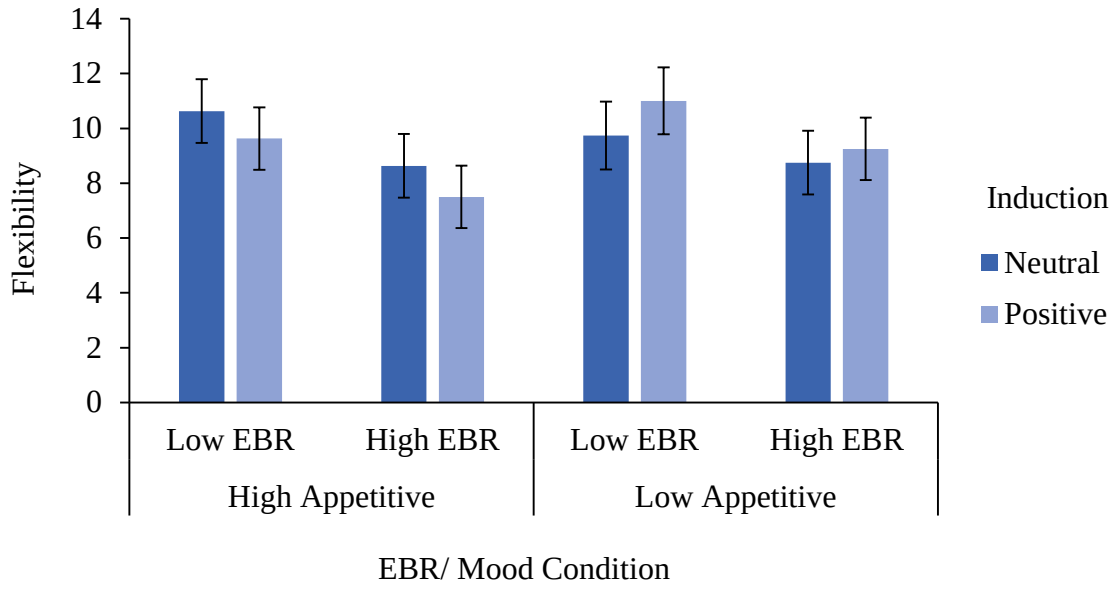


Figure 4.6. *Flexibility in divergent thinking performance dependent on induction, mood condition, and neutral EBR. Error bars reflect one standard error above and below the mean.*

Although common practice in research examining EBR, dictomising this variable by performing a median split may be problematic because it results in a loss of statistical power, which can increase the chance of Type II error (Aiken & West, 1991). Therefore, regression analysis was also conducted to examine whether neutral EBR moderated the effect of the positive mood inductions on flexibility.

Flexibility for the positive induction was entered as the dependent variable. In the first step, neutral flexibility and neutral EBR were entered as continuous predictor variables. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect the low (=0) and high appetitive (=1) conditions. In the second step, a product term was also entered, to reflect the interaction between neutral EBR and mood condition. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

There was a significant overall model effect at step one [R^2= .91, F(3,26) = 41.87, p < .001]. Individual predictors for this model are displayed in Table 4.11, which demonstrates that neutral divergent thinking and mood condition significantly predicted divergent thinking scores

for the positive induction. Examination of the coefficients suggests that flexibility for the positive induction was greater for those demonstrating greater flexibility for the neutral induction and for those in the high appetitive condition.

Table 4.11. *Coefficients and significance values for individual predictors in regression models for moderation of post-induction flexibility by mood condition and pre-induction EBR*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Flexibility	.85	.09	.87	10.09	<.001
Mood Condition	1.73	.52	.27	3.32	.003
EBR	-.018	.02	-.07	-.84	.409
Step 2					
Flexibility	.86	.09	.88	9.65	<.001
Mood Condition	1.73	.53	.27	3.26	.003
EBR	.00	.07	.15	.05	.959
Mood Condition by EBR	-.01	.04	-.09	-.32	.749

However, additional variance was not explained by adding the interaction term for pre-induction EBR and mood condition [$\Delta R^2 = .00$, $F(1,15) = .10$ $p = .749$], suggesting regression results are in line with ANOVA analysis (Table 4.10)

Therefore, these findings do not replicate the results of Chermahini and Hommel (2012), where baseline EBR was found to moderate the influence of positive mood on flexibility in divergent thinking.

For fluency, elaboration, and originality, ANOVAs using the dictomised EBR variable also revealed no significant main or interaction effects, including for the pertinent induction by mood condition interaction ($F's \leq 2.68$, $p's \geq .113$).

Regression models using EBR as a continuous variable also found no evidence that a mood condition by pre-induction EBR interaction predicted fluency, elaboration, or originality (F's ≤ 2.26, p's $\geq .146$).

4.5. Discussion

4.5.1. Positive Mood and Divergent Thinking

The first aim of the present study was to examine the moderating role of appetitive motivation in relation to the influence of positive mood on divergent thinking. Only positive mood low in appetitive motivation was hypothesised to enhance performance on the divergent thinking task. This was found to be the case, as flexibility was significantly greater only as a result of the positive mood induction that was low in appetitive motivation. Although a similar effect has been demonstrated previously by studies examining the effect of positive mood inductions on divergent thinking (R. S. Friedman et al., 2007; Tan & Qu, 2014; Vosburg, 1998), these studies do not take into account the motivational intensity of positive mood induced. Therefore, based on the results of the current study, it is important that future work does take into account the motivation intensity of positive mood.

It was also hypothesised that positive mood high in appetitive motivation would have no effect or result in a trend towards reduced divergent thinking task performance. This was also found to be the case, as flexibility was found to be (significantly) reduced as a result of this mood induction. Therefore, findings are in line with the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect low in appetitive motivation results in broader and more flexible cognition, whilst narrower and more stable cognition is argued to result for positive affect that is high in appetitive motivation. It is also in line with suggestions of an antagonistic balance between flexibility and stability in cognitive control (Goschke, 2000). Therefore, it may be especially important for future studies to take into account the motivational intensity, as positive mood states that are high and low in appetitive motivation may have opposing effects on performance on divergent thinking tasks.

This is the first study to demonstrate this moderating effect for motivational intensity in relation to the influence of positive mood on creativity. However, this has previously been demonstrated in other fields of cognitive psychology, such as in relation to attentional scope. For example, positive affect low in appetitive motivation has been demonstrated to result in a more global focus of attention, whilst a more local focus of attention results from positive affect high in appetitive motivation (Gable & Harmon-Jones, 2008b). In addition, motivational intensity has been demonstrated to moderate the influence of positive affect on the balance between flexibility and stability on cognitive control tasks. For example, positive affect low in appetitive motivation has been demonstrated to result in enhanced performance on an

attentional set-shifting task (i.e., switching attention to a new attentional set), whilst performance is reduced as a result of positive affect high in appetitive motivation (Liu & Wang, 2014).

The correlations between positive affect and divergent thinking were also explored within the present study. A slight non-significant trend towards a positive relationship between deactivated positive affect and flexibility (and fluency) was observed. This is in line with previous findings that increases in positive affect following a positive mood induction were associated with increases in flexibility in divergent thinking (Chermahini & Hommel, 2012). However, it should be noted that this study did not examine activated and deactivated positive affect separately. In the present study, there were significant positive relationships between deactivated positive affect and divergent thinking, but flexibility was found to be (non-significantly) negatively related to activated positive affect, which is in line with findings observed in Study 1. Therefore, the general direction of the relationships observed between positive affect and divergent thinking in the present study reflect the effects found for positive inductions in the different mood conditions.

4.5.2. Neurobiological Mechanisms

The second aim of the present study was to examine the possible neurobiological mechanisms underlying the influence of positive mood on divergent thinking, using an indirect physiological measure of dopamine activity (i.e., EBR). Chermahini and Hommel (2012) previously demonstrated that EBR was increased following a positive mood induction (presumed to be low in appetitive motivation), and was suggested to reflect greater activity in the nigrostriatal pathway. However, pharmacological studies have demonstrated that manipulations assumed to target activity in either the mesocorticolimbic or the nigrostriatal pathways both increase EBR (Elsworth et al., 1991). As positive mood high in appetitive motivation has been suggested to result greater mesocorticolimbic dopamine activity, an exploratory approach was taken to examine the effect of positive mood inductions in the present study. In contrast to Chermahini and Hommel's (2012) study, EBR was actually found to be lower as a result of the positive mood induction that was low in appetitive motivation.

4.5.2.1. Positive Mood and EBR

In contrast, EBR was found to be greater for the high appetitive positive mood induction compared to the neutral mood induction. Based on the suggestion that positive mood high in

appetitive motivation is associated with an increase in dopamine activity in the mesocorticolimbic pathway, whilst positive mood low in appetitive motivation is associated with other neural substrates (Depue & Collins, 1999; Knutson & Cooper, 2005), EBR may be suggested to reflect an increase in dopamine activity in the mesocorticolimbic pathway. The finding that positive mood inductions that were high and low in appetitive motivation had opposing effects on EBR, is in line with the finding that these mood inductions also have opposing effects on divergent thinking task performance. Therefore, this is in line with suggestions that the antagonistic balance between flexibility and stability in cognitive control is mediated by a reciprocal relationship between greater dopamine activity in the basal ganglia and prefrontal cortex (Cools & D'Esposito, 2011).

The correlations between positive affect and EBR were also explored for both neutral and positive inductions, but no significant relationships were observed. There was a very slight non-significant positive trend for activated positive affect and EBR, which is in line with the finding that EBR was greater in the high appetitive condition (resulting in an increase in activated positive affect). Interestingly, the direction of this trend is not in line with the negative relationship that was observed between these variables in Study 1. However, the positive relationship observed between EBR and activated positive affect in the present study was found to occur during the positive inductions, whilst the negative relationship in Study 1 was found only at the pre-induction time point. Therefore, as the mood inductions were not effective in Study 1, it is possible that a positive relationship may have been observed at the post-induction time point, if these had been effective.

4.5.2.2. EBR and Divergent Thinking

The relationships between EBR and divergent thinking were also examined in the neutral condition. This was based on Chermahini and Hommel's (2010, 2012) findings of an inverted U-shape relationship between these variables when assessed at baseline, and it was hypothesised that these findings would be replicated. However, a significant negative linear relationship was observed in the present study, which is not in line with hypotheses. Despite this, this was found to be consistent across flexibility, fluency, and elaboration characteristics of divergent thinking. This is in line with Study 1, where a (non-significant) negative linear trend was also observed between flexibility and EBR at the pre-induction time point. In Study 1, it was suggested that this may have reflected the fact that the mean EBR for the sample was higher compared to in previous work. This may also be the case in the present study (M = 22.09

cf. 14.10 for Chermahini & Hommel, 2010), thus positioning participants at the negative slope of the hypothesised inverted U-shape.

The amount of variance explained by adding quadratic terms to linear models was found to be small in the present study, and did not approach significance ($p \sim 0.200$). This is an important point because it suggests that the previously demonstrated findings of an inverted U-shape (Chermahini & Hommel, 2010, 2012), may not be reliable and may depend on other factors. However, sample size for this type of analysis was small in the present study, and it may be suggested that this did not allow sufficient variation in EBR to allow a quadratic relationship to be observed (K. R. Murphy, Myors, & Wolach, 2014). Although, previous studies have used sample sizes similar to that of the present study ($N = 32$ cf. 35 and 33 in Chermahini & Hommel, 2012), and have still consistently demonstrated a quadratic relationship in a number of separate experiments. Furthermore, a larger sample was used in Study 1, and this was comparable to the combined analysis performed by Chermahini and Hommel (2012) ($N = 69$ cf. 67), yet an inverted U-shape relationship was still not observed.

It may be the case that the failure to find a quadratic relationship between EBR and divergent thinking performance at baseline, may reflect differences in sample characteristics compared to previous studies (Chermahini & Hommel, 2010, 2012). However, the present study had a similar gender distribution to these studies, and although age was higher in the present study ($M = 41.91$ years cf. ~ 20 years in Chermahini & Hommel, 2010), Study 1 had a sample with a more comparable average age ($M = 22.51$ years). In addition, samples in previous studies were recruited from Western universities (Chermahini & Hommel, 2010, 2012), suggesting similar cultural norms to the sample in the present study. Therefore, it is unclear why there are differences in mean EBR between samples, although one possible candidate might be intelligence, which has been demonstrated to be related to dopamine activity in previous studies (Previc, 1999).

Alternatively, the negative linear relationship between pre-induction EBR and divergent thinking may reflect the relationship between mesocorticolimbic dopamine activity and divergent thinking. This is opposed to reflecting the negative slope of an inverted U-shaped relationship between nigrostriatal dopamine activity and divergent thinking, which was based on the assumption that baseline EBR primarily reflects dopamine activity in the basal ganglia (Jongkees & Colzato, 2016). However, this raises the question – are individual differences in nigrostriatal activity reflected by baseline EBR in Chermahini and Hommel's (2012) study, and if so why is nigrostriatal activity reflected in this study, whilst individual differences in

mesocorticolimbic activity are reflected in EBR in the present study? It could be suggested that EBR is also reflecting mesocorticolimbic activity in Chermahini and Hommel's (2012) study, but this is not in line with findings of positive relationships between EBR and flexibility in divergent thinking.

Specifically, Chermahini and Hommel (2012) found that increases in EBR following their positive mood induction were correlated with increases in divergent thinking performance. The relationships between these variables during the positive induction were explored in the present study. This, again, took an exploratory approach, due to the suggestion that pharmacological manipulations increasing dopamine activity in the mesocorticolimbic and nigrostriatal pathways may both increase EBR (Elsworth et al., 1991). A negative relationship was observed between post-induction EBR and divergent thinking, which was found to be the case for flexibility, fluency, and originality. A negative relationship was also found between increases in EBR and increases in divergent thinking for the positive mood induction in Study 1. Therefore, these findings are in line with the suggestion that increases/decreases in mesocorticolimbic dopamine activity may underlie the effects of positive mood induction that are high and low in appetitive motivation on divergent thinking.

4.5.2.3. EBR, Mood, and Divergent Thinking

Chermahini and Hommel (2012) also found that baseline EBR moderated the influence of their positive mood induction on divergent thinking task performance. This was such that enhanced divergent thinking as a result of the induction was found to occur only for those with a lower baseline EBR. Therefore, this is in line with their findings of an inverted U-shaped relationship between EBR and divergent thinking, and suggests that enhanced divergent thinking as a result of positive mood depends on individual differences in baseline EBR. In the present study, it was hypothesised that only those with a lower EBR in the neutral induction would demonstrate enhanced divergent thinking for the positive mood induction that was low in appetitive motivation. However, neutral EBR was not found to moderate the effect of positive mood that was high or low in appetitive motivation for any characteristics of divergent thinking, which was not surprising considering the lack of quadratic relationship observed between EBR and divergent thinking performance in the neutral induction.

The neurosychological theory of positive affect (Ashby et al., 1999) argues that positive mood enhances creativity due to an increase in dopamine activity, which is suggested to allowing dominant cognitive sets to be overcome, and to facilitate the activation of non-dominant

cognitive sets. The present study provides evidence that dopamine activity is related to positive mood, as well as evidence that this is also related to performance on divergent thinking tasks. These findings were primarily related to the flexibility characteristic of divergent thinking – ideas from different categories, which was in line with expectations. However, fluency (i.e., the number of ideas) and elaboration (i.e., detail of an idea) were also both found to be negatively related to EBR, and this was consistent when assessed for both neutral and positive inductions. Although, there were no significant findings for elaboration (i.e., the amount of detail provided for ideas).

When completing the divergent thinking task in the present study – the Alternate Uses Task – a participant must produce as many alternate uses for a household object (e.g., a pencil) as possible. Therefore, in line with the neuropsychological theory of positive affect, participants are required to overcome the dominant cognitive sets that are associated with this object (e.g., relating to writing or drawing), and activate non-dominant cognitive sets (e.g., use as a weapon). It seems likely that these processes are reflected in the flexibility characteristic of divergent thinking (i.e., the number of different semantic categories used), as well as fluency, as the more categories accessed would increase the total number of uses produced. However, it is somewhat unexpected that these processes may also increase elaboration, as this characteristic requires focusing on only a single use for a period of time, which may not directly benefit from enhanced access to less dominant sets.

4.5.2.4. Issues with Design

Finally, it is important to note that the mood inductions used in the present study were demonstrated to be effective, as only the positive mood induction in the low appetitive condition resulted in an increase in deactivated positive affect, whilst only the positive mood induction in the high appetitive condition resulted in an increase in activated positive affect. The stimuli and mood induction procedure were the same as those used in Study 1, but some minor changes were made, including participants being alone and wearing headphones during the mood induction. In addition, the design of the study was simplified compared to Study 1, which reduced the length of experimental sessions. Rather than comparing performance before and after a positive mood induction, participants completed a neutral and positive induction in two separate sessions. Furthermore, the number of tasks completed by participants within the sessions was reduced compared to Study 1. It is likely that these changes made to the mood

induction procedure and design of the study facilitated engagement with the induction, resulting in more effective changes to mood.

Another change to the design of Study 1 that may have contributed to effectiveness of the mood induction procedure was the use of a different response format for the measure of mood. In Study 1, a four-point response scale was used, which may not have been suitable to reflect subtle changes in mood resulting from the induction. Instead, a visual analogue scale was used in the present study, which assessed affect on a scale from one to one-hundred, providing a more sensitive measure of mood state. In Study 1, it was also suggested that the use of the mood measure (the UMACL) may have obscured relationships between deactivated positive affect and other variables within the study. This was because the Hedonic Tone factor used to represent deactivated positive affect assesses only the valence component of positive affect. However, the mood measure used in the present study (the 12-PACS) has separate factors for different levels of activated and deactivated positive affect, based on both valence and activation properties. Therefore, this measure may be suggested to provide a more valid representation of these types of positive affect.

4.5.3. Conclusions

The present study aimed to examine the moderating role of appetitive motivation in relation to the influence of positive mood on divergent thinking. Appetitive motivation was found to moderate the influence of positive mood on divergent thinking, such that performance was enhanced for the positive induction low in appetitive motivation, but attenuated for the positive induction high in appetitive motivation. This supports suggestions from the motivational intensity model (Gable & Harmon-Jones, 2010) that positive affect low in appetitive motivation promotes broader more flexible cognition, whilst positive affect high in appetitive motivation promotes narrower and more stable cognition. Although previous work has examined the influence of positive mood on divergent thinking, it has not taken into account the motivational intensity of the inductions used (e.g., Chermahini & Hommel, 2012). Therefore, this is the first study to demonstrate that the effect of positive mood on divergent thinking may be moderated by motivational intensity.

Another aim of the present study was to examine dopamine activity as a potential mechanism underlying the effect of positive mood on divergent thinking. EBR was found to be lower for the positive mood induction low in appetitive motivation, but greater for the positive mood induction high in appetitive motivation. However, previous research has found that positive

mood (presumably low in appetitive motivation) increased EBR, possibly reflecting greater nigrostriatal activity (Chermahini & Hommel, 2012). EBR has also been demonstrated to be increased as a result of manipulations targeting mesocorticolimbic activity (Elsworth et al., 1991). Therefore, increases/decreases in EBR may be proposed to reflect this activity in the present study, in line with suggestions that positive affect high in appetitive motivation is related to greater mesocorticolimbic activity (Depue & Collins, 1999). This may explain the influence of mood inductions on divergent thinking, as a reciprical relationship between activity in the basal ganglia and prefrontal cortex is suggested to mediate flexibility vs. stability in cognition (Cools & D'Esposito, 2011).

An inverted U-shaped relationship between EBR and divergent thinking performance for the neutral induction was not observed, as was expected based on previous research (Chermahini & Hommel, 2010). Instead, there was a negative linear relationship between these variables, which may reflect a higher mean EBR for the sample compared to previous studies, situating participants in the negative slope of the inverted U-shaped relationship with divergent thinking. This is in line with findings from Study 1, and may explain the negative relationship observed between EBR and divergent thinking task performance for the positive induction. Alternatively, it may be suggested that EBR in the neutral condition reflects mesocoritcolimbic (as opposed to nigrostriatal) dopamine activity, which would also explain these findings. EBR for the neutral induction was also not found to moderate the influence of positive mood on divergent thinking, as has been previously demonstrated (Chermahini & Hommel, 2012). This is is in line with the lack of quadratic relationship observed between these variables in the neutral induction.

5. Study 3 – Does appetitive motivation moderate the association between positive mood, novelty preference, and flexibility in set-shifting?

5.1. Abstract

Dreisbach and Goschke (2004) demonstrated that positive affect (induced using briefly presented positive images) resulted in greater flexibility on an attentional set-shifting paradigm. Specifically, this was in terms of reduced perseveration, but increased distractibility, and was suggested to be due to an increased novelty bias. Liu and Wang (2014) found that this pattern of results indicating increased flexibility only occurred for positive images low in appetitive motivation. In contrast, positive images high in appetitive motivation were found to result in reduced flexibility (i.e., increased perseveration and reduced distractibility), which is in line with the motivational intensity model (Gable & Harmon-Jones, 2010). Based on these findings, Study 3 aimed to examine the effects of more enduring positive mood states on this paradigm, and whether effects were driven by an increased novelty bias.

Sixty-five participants took part in a laboratory-based experimental study and were randomly assigned to a mood condition (neutral, high appetitive, or low appetitive). Inductions used the same stimuli as Study 2, as well as the same measure of positive affect at pre- and post-induction timepoints. Following inductions and the affect measure, participants completed the set-shifting task, which involved categorising a target stimulus, presented simultaneously with a distractor stimulus. Two blocks of trials were adapted from the original paradigm to assess perseveration and distractibility in attentional switching, and two new blocks of trials were added to isolate the effects of an increased novelty bias: engaging novelty and ignoring novelty.

ANOVAs demonstrated that mood inductions were effective, but that there was no effect of the mood inductions on perseveration or distractibility, which suggests that effects on flexibility in cognitive control may be limited to transient emotional responses (not more enduring mood states). Engaging novelty was found to be enhanced for the low appetitive positive mood, suggesting greater flexibility, which is in line with the motivational intensity model. However, a similar pattern of results (although non-significant) were observed for high appetitive positive mood. Despite this, no effects of mood inductions were found when ignoring novelty, which may have been because less attentional control was required for this condition.

5.2. Introduction

The previous studies (Studies 1 and 2) aimed to explore findings regarding the influence of positive mood on cognition, specifically in relation to performance on creativity tasks (Chermahini & Hommel, 2012; R. S. Friedman et al., 2007; Tan & Qu, 2014). However, positive mood has also been found to influence performance on tasks designed to assess more basic and fundamental cognitive processes. For example, positive mood impairs performance on the Tower of London paradigm, which assesses planning (Oaksford, Morris, Grainger, & Williams, 1996), as well as performance on a task-switching paradigm, which assesses participants' ability to switch between different sets of rules when responding to stimuli (L. H. Phillips et al., 2002). However, positive mood is not always detrimental to performance on cognitive control tasks, as performance has been found to be enhanced on the Stroop paradigm, which assesses participants' ability to overcome interference from conflicting stimuli (Kuhl & Kazen, 1999).

Therefore, studies do provide some evidence that positive mood has an effect on cognitive control tasks that assess basic and fundamental cognitive processes, but this effect is not consistent, in terms of resulting in impaired or enhanced performance across tasks. This may be due to the fact that the tasks used in these studies may engage a number of different component processes that are involved in cognitive control. For example, Miyake and Friedman (2012) suggest that performance on tasks assessing cognitive control involve three primary processes. This includes the ability to shift attention between cognitive sets, update working memory content, and to maintain task-relevant representations in the face of interference. Based on this, positive mood could be suggested to differentially affect these component processes, resulting in impaired or enhanced performance, dependent on the processing demands of the specific task being that is being examined.

5.2.1. Flexibility and Stability

Dreisbach and Goschke (2004) argue that one way in which positive affect may influence performance in cognitive control tasks is by modifying the antagonistic balance between flexibility and stability. This is based on the proposition that a shielding-shifting dilemma exists in goal-directed behaviour, which places multiple constraints on cognitive control processes. Specifically, it is necessary for representations relating to active goals to be maintained and shielded from distraction, but also for an individual to be able to update, disengage, and shift attention to new goals when necessary (Goschke, 2000). Therefore, a trade-off is required

between stability and flexibility in cognitive control, which may result in complimentary costs and benefits for cognition. Specifically, stability may be beneficial for shielding goals, but could be costly in terms of promoting perseverative behaviour, whilst flexibility is proposed to be beneficial for shifting goals or adaptive updating to environmental cues, but may be costly in terms of increasing distractibility and impulsive behaviour.

Dreisbach and Goschke (2004) argue that positive affect may influence cognitive control processes by promoting flexibility (vs. stability), which facilitates goal-shifting. This is in line with the proposition that positive affect serves as a signal that goal-pursuit has run better than expected, providing the adaptive function of promoting a more exploratory mode of behaviour, which allows the engagement in new goals and opportunities (Carver, 2003). Therefore, positive mood may be expected to enhance performance on tasks requiring flexibility (i.e., facilitating updating and shifting between different rules of task-switching paradigms), but attenuate performance on tasks requiring stability (i.e., reducing maintenance of task-sets and suppression of interference from distracting information on the Stroop paradigm). However, as outlined above, this has not been found to be the case, with positive mood inductions being found to have the opposite effects than those that would be expected on these paradigms (e.g., Kuhl & Kazen, 1999; L. H. Phillips et al., 2002).

5.2.2. Novelty Bias

To explain these unexpected findings, Dreisbach and Goschke (2004) suggest that positive affect results in greater flexibility as a result of a single mechanism – an increased novelty bias. Specifically, positive affect may be beneficial in terms of facilitating processes involved in disengaging from current goals, updating representations, and shifting attention to new goals. However, an increased novelty bias may be costly, in terms of attention being more easily captured by novel information, which is not relevant to the current goal. Therefore, the tasks used in previous studies may not capture the effects of an increased novelty bias on cognitive control processes, which may explain the unexpected findings in these studies. For example, L. H. Phillips et al.'s (2002) task-switching paradigm required participants to switch between different rules, rather than disengaging and switching to a novel rule. Furthermore, the Stroop paradigm that was used by Kuhl and Kazen (1999) did not involve interference or distractors that were specifically relating to novel stimuli.

Therefore, a new set-shifting paradigm was implemented by Dreisbach and Goschke (2004), which required participants to switch to a new attentional set (cf. more complex task-switching

paradigms used in earlier studies). Participants categorised a target stimulus, which was presented simultaneously with a distractor stimulus. These were defined by pre-specified relevant and irrelevant colours. After a number of trials, participants underwent a switch, which involved responding to different colour stimuli (see Figure 5.1). In a perseveration condition, the target became a novel colour and the distractor was the previously relevant colour. Here, a novelty bias that facilitates flexibility should enhance switching because attention is drawn to the novel target, and also, simultaneously, perseveration of the previous target (now the distractor) is attenuated. However, in a distraction condition, the target became the previously irrelevant colour and the distractor was a novel colour. Therefore, a novelty bias facilitating flexibility should be detrimental to switching because attention is drawn to the novel distractor, which results in increased distractibility.

To examine the influence of positive affect on this paradigm, positive or neutral images were briefly presented prior to each trial. Response times (RTs) were measured and switch costs were calculated (mean RTs before the switch were subtracted from mean RTs after the switch) separately for perseveration and distraction conditions. Positive affect was found to result in lower switch costs than neutral affect in the perseveration condition, but greater switch costs in the distraction condition. This suggests that positive affect enhances flexibility (vs. stability) in cognitive control, by increasing a novelty bias, and reducing perseveration, which occurs at the cost of increased distractibility. Therefore, this is in line with the proposition that positive affect results in greater flexibility, as it acts as a signal to engage in new goals and opportunities. Furthermore, these results suggest that previous studies examining the influence of positive mood on tasks assessing executive functions may produce unexpected results due to a failure to take into account the underlying mechanism of an increased novelty bias.

The suggestion that positive affect may result in an increased novelty bias is supported by work conducted by Frober and Dreisbach (2012). An adapted version of the Stroop task was used in this study, which required participants to categorise target words, whilst novel or familiar pictures were simultaneously presented as distractors. Participants were assigned to either a neutral or positive condition, and affect was manipulated using images that were briefly presented prior to each trial. RTs were measured and these were found to be increased for novel distractors across the conditions, but this increase was greater in the positive condition. This supports the idea that a novelty bias may underlie the effect of positive affect on Dreisbach and Goschke's (2004) the set-shifting paradigm, such that this facilitates change to the novel target

for the perseveration condition, but is detrimental for the distraction condition as attention is captured by the novel distractor.

5.2.3. The Reward-as-Motivation Hypothesis

Whilst positive affect is suggested to facilitate an exploratory mode of behaviour, potential rewards or incentives (i.e., appetitive goals) are argued to signal that a more exploitive mode of behaviour is required. This has become known as the reward-as-motivation hypothesis, as this suggests that this signal enhances motivation to engage in effortful control. This too is suggested to serve an adaptive function, in terms of optimising task performance and maximising the likelihood of obtaining the reward (Aston-Jones & Cohen, 2005). Within this account, it is argued that it is specifically positive affect that is unrelated to a task, which results in greater flexibility in cognitive control and facilitates an exploratory mode of behaviour. However, performance-dependant reward incentives are proposed to promote greater stability in cognitive control. Therefore, this may be beneficial in terms of facilitating the maintenance of goal-relevant representations, but costly in terms of increasing perseveration.

To test this hypothesis, the influence of performance-dependent reward incentives has been examined in relation to Dreisbach and Goschke's (2004) set-shifting paradigm. Muller, Dreisbach, Goschke, et al. (2007) compared switch costs for trials that were proceeded by a neutral image to those that were proceeded by a cue signalling that a monetary incentive was available for good performance – indicated by faster responses and fewer errors. For trials preceded by neutral images, there were no differences in RT switch costs for the perseveration compared to the distraction condition. However, switch costs were significantly lower in the distraction compared to the perseveration condition, for the trials that were preceded by cues for monetary incentives. This suggests that stability (vs. flexibility) was greater for reward incentives, due to a reduced novelty bias, which reduced distractibility, but increased perseveration. Therefore, these findings are in line with the reward-as-motivation hypothesis, and indicate that reward incentives facilitate a more exploitive mode of behaviour, which optimises task performance, and enhances appetitive goal-pursuit.

5.2.4. The Motivational Intensity Model

However, the motivational intensity model of positive affect proposes that the influence of positive affect on cognition depends on the motivational intensity (Gable & Harmon-Jones, 2010). It is argued that positive affect high in appetitive motivation results in a narrower

processing mode, which is beneficial for exploitive behaviour during goal-pursuit. However, positive affect that is low in appetitive motivation results in a broader processing mode, which is beneficial for exploring new goals and opportunities. Although this model refers to attentional and cognitive scope, it can be extended to apply to the balance between flexibility and stability in cognitive control. This is such that, positive affect high in appetitive motivation may be suggested to result in greater stability in cognitive control, whilst positive affect low in appetitive motivation may result in greater flexibility. Therefore, unlike the reward-as-motivation hypothesis, this suggests that it is the motivational intensity of positive affect, as opposed to the active pursuit of an appetitive goal or reward incentive, which influences cognitive control.

The motivational intensity model of positive affect is supported by a study conducted by Liu and Wang (2014). Performance on Dreisbach and Goschke's (2004) set-shifting paradigm was compared for positive affect that was high or low in appetitive motivation and neutral affect. This was induced (respectively) using images of household objects, desserts, and landscapes, and these images were presented briefly prior to each trial. Dreisbach and Goschke's (2004) earlier findings were replicated for positive mood low in appetitive motivation, suggesting greater flexibility (at the cost of increased distractibility). However, positive affect high in appetitive motivation was found to result in greater stability (at the cost of increased perseveration), which replicates the findings of Muller, Dreisbach, Goschke, et al. (2007). Therefore, this supports the motivational intensity model, and suggests that positive affect high in appetitive motivation results in greater stability in cognitive control, even when the motivational affective state is not inherent to task performance.

5.2.5. Present Study

To date, studies that have examined the influence of positive affect on cognitive control on Dreisbach and Goschke's (2004) set-shifting paradigm have used images presented briefly prior to each trial to induce divergent affective states. This is likely to produce only transitory emotional responses, as opposed to longer lasting changes in mood. This is supported by the fact that in their original study, Dreisbach and Goschke (2004) found that the images displayed did not induce any conscious changes to affective state (i.e., comparison of self-reported mood ratings before and after the task). Therefore, it may be the case that the effect observed on this paradigm arose specifically from the tight temporal coupling of affective images and the task responses. As such, it is currently unclear whether previous results occur only as a transient

effect in response to the emotional images or may also occur under more enduring mood states. This is an important area of investigation, as mood states may guide behaviour over longer periods of time in everyday life (Rolls, 2010).

Therefore, the first aim of the present study is to examine whether positive mood (cf. transitory emotional responses to briefly presented stimuli) influences the balance between flexibility and stability in cognitive control, and whether this is moderated by appetitive motivation, which is predicted by the motivational intensity model. To do this, performance on Dreisbach and Goschke's (2004) set shifting paradigm will be compared following positive (high and low in appetitive motivation) and neutral mood inductions. It is expected that findings will be in line with those from previous studies that have used brief emotional manipulations (i.e., Liu & Wang, 2014). Therefore, it is hypothesised that positive mood low in appetitive motivation will enhance flexibility in cognitive control at the cost of greater distractibility (decreased perseveration and increased distraction switch costs). Conversely, it is also hypothesised that positive mood high in appetitive motivation will enhance stability in cognitive control and reduce distractibility (increased perseveration and decreased distraction switch costs).

Although Dreisbach and Goschke (2004) suggest that the influence of positive mood on flexibility in this set-shifting paradigm is driven by a novelty bias, there are processes related to cognitive control that may contribute to switch costs. For example, the authors acknowledge that positive affect may result in an increase in switch costs within the distraction condition of this paradigm, which is due to persisting inhibition of the previously irrelevant distractor in post-switch trials, as this is now the relevant target colour. However, it was suggested that if this explanation was driving effects in this condition, then more effective inhibition as a result of positive affect would also reduce interference of distractors in the pre-switch trials. Therefore, assuming inhibition impacts RTs to an equal degree in pre- and post-switch trials, the authors argued that the overall effect will be zero. Hence, any differences between switch costs in the distraction condition across neutral and positive affect conditions would most likely be due to other mechanisms, such as the proposed novelty bias.

Furthermore, trials within this paradigm can be compatible (i.e., the target and distractor associated with the same response) or incompatible (i.e., the target and distractor are associated with different responses). Therefore, this should result in a compatibility effect, where RTs are increased on incompatible compared to compatible trials, due to increased interference from the incompatible distractors. An enhanced inhibition explanation of increased switch costs in the distraction condition as a result of positive affect would predict that compatibility effects

would be reduced on pre-switch trials across the switch conditions. This is because positive affect would be assumed to enhance inhibition of the distractor, thus reducing increased interference on incompatible trials. In contrast, a novelty bias explanation would predict equal compatibility effects for positive and neutral affect on pre-switch trials, as interference is not being affected by positive affect, and targets and distractors are equally novel across compatible and incompatible trials. However, Dreisbach and Goschke (2004) found that compatibility effects did not vary between affect conditions, leading them to conclude that a novelty bias account best explained the influence of positive affect on this paradigm.

Despite this, there are also other processes relating to flexibility in cognitive control that may contribute to switch costs in this paradigm. In the perseveration condition, it is argued that a novelty bias facilitates the switch to a new colour. However, this switch also requires inhibition and disengagement from the previously relevant target colour, as this is then the distractor on post-switch trials. In contrast, the distraction condition requires re-engagement and dis-inhibition of the previously irrelevant distractor colour, which is then the target on post-switch trials. Each of these sets of processes are not required in the alternate switch condition and are distinct from the novelty bias mechanism that is suggested to underlie the influence of positive affect on switch costs. Furthermore, Tharp and Pickering (2011) found that enhanced performance on a working memory paradigm reduced switch costs in both switch conditions of this paradigm. The authors suggested that this may reflect faciliatory benefits, in terms of more flexible updating to the relevant colour post-switch in both conditions. Therefore, there are other possible mechanisms, aside from an increased novelty bias, that may influence flexibility on this paradigm as a result of positive affect.

Therefore, the second aim of the present study is to examine whether findings within this paradigm are specifically related to a novelty bias. To do this, two new switch conditions will be included in the set-shifting paradigm. First, an engaging novel condition, in which the target will switch to a novel colour, but the distractor colour will remain the same. This should eradicate any influence of positive affect on flexibility required for disengagement and inhibition of the previously relevant distractor in the perseveration condition. Second, an ignoring novel condition, in which the target colour will remain the same, but the distractor colour will be novel. This should eradicate any influence of positive affect on flexibility required for re-engagement and dis-inhibition of the previously irrelevant distractor in the distraction condition. It is hypothesised that positive mood low in appetitive motivation will enhance flexibility, at the cost of increased distractibility (decreased engaging novel and

increased ignoring novel switch costs). In contrast, it is also hypothesised that positive mood high in appetitive motivation will enhance stability and decreased distractibility (increased engaging novel and decreased ignoring novel switch costs).

To further investigate the claim that the effects of positive affect are driven by a novelty bias, a number of novel probes were introduced to replace standard pre-switch trials in each switch condition block. Within these trials, the distractor was a novel colour compared to the colour of distractors on other typical pre-switch trials, whilst the target remained unchanged. Therefore, if the observed effects of positive affect are driven by a novelty bias, then RTs should be increased on trials with novel probes compared to other pre-switch trials. Compared to standard pre-switch trials, those with novel distractors should not require any additional processes in terms of engagement and inhibition, other than to ignore a novel distractor colour. So, if effects are driven by a novelty bias, this should result in greater attentional capture in pre-switch trials as a result of positive affect, in the same way as is proposed to occur on post-switch trials. Therefore, it is hypothesised that positive mood low in appetitive motivation will result in relatively slower RTs on novel probe trials, reflecting an increased novelty bias. However, as distraction will be reduced, it is hypothesised that positive mood high in appetitive motivation will result in relatively faster RTs on novel probe trials, reflecting a decreased novelty bias.

5.2.6. Aims and Hypotheses

1. To examine whether positive mood (cf. transitory emotional responses to briefly presented stimuli) influences the balance between flexibility and stability in cognitive control, and whether this is moderated by appetitive motivation.

   i) It is hypothesised that positive mood low in appetitive motivation will enhance flexibility in cognitive control at the cost of greater distractibility (decreased perseveration and increased distraction switch costs).

   ii) It is also hypothesised that positive mood high in appetitive motivation will enhance stability in cognitive control and reduce distractibility (increased perseveration and decreased distraction switch costs).

2. To examine whether findings within this paradigm are specifically related to a novelty bias.

i) It is hypothesised that positive mood low in appetitive motivation will enhance flexibility, at the cost of increased distractibility (decreased engaging novel and increased ignoring novel switch costs).

ii) It is also hypothesised that positive mood high in appetitive motivation will enhance stability and decreased distractibility (increased engaging novel and decreased ignoring novel switch costs).

iii) It is hypothesised that positive mood low in appetitive motivation will result in relatively slower RTs on novel probe trials, reflecting an increased novelty bias.

iv) It is hypothesised that positive mood high in appetitive motivation will result in relatively faster RTs on novel probe trials, reflecting a decreased novelty bias.

5.3. Method

5.3.1. Participants

Sixty-five undergraduate students (21 males, 44 females), aged 18-38 years (*M* = 21.03 years, *SD* = 4.58) were recruited from a London university, and received course credit for participation. Participants were randomly assigned to a mood induction condition: neutral (n = 21), positive mood high in appetitive motivation (*n* = 22), or positive mood low in appetitive motivation (*n* = 22). No participants had any problems with their colour vision. The study was approved by the University Research Ethics Committee, and all participants provided informed consent at the start of the study, and were fully debriefed at the end of the study.

5.3.2. Measures

5.3.2.1. Mood Induction

The vignettes and music used for the positive mood inductions were the same as in Study 2, and the same procedure was followed. However, participants also completed a mood induction booster session approximately half way through the set-shifting paradigm, in which one scenario was presented for a second time and participants engaged in mental imagery and listened to the same piece of music again for approximately 4mins. Mood booster sessions have been used in previous studies examining the influence of mood on cognition, in order to ensure that mood carries across the entire experimental period (e.g., Martin & Kerns, 2011).

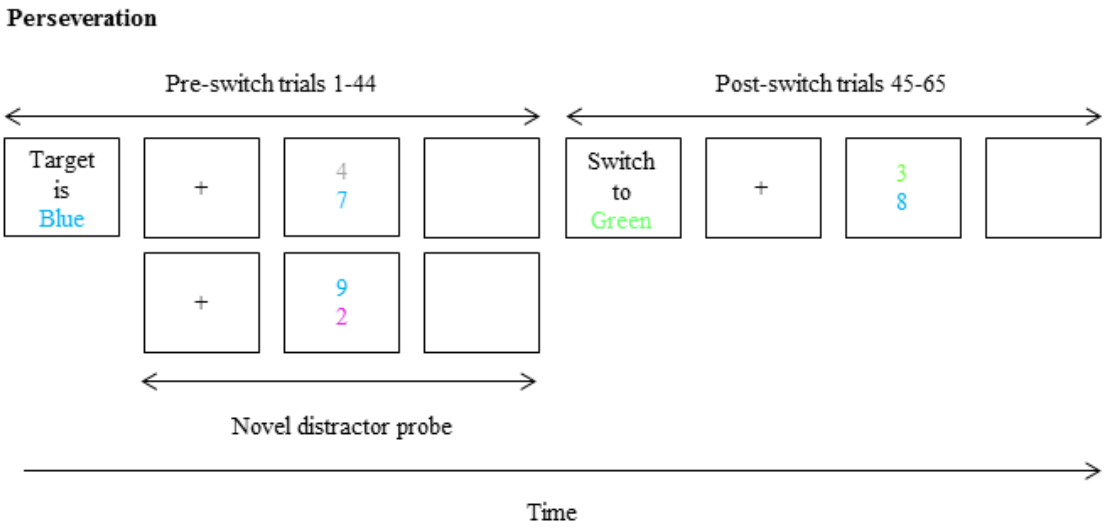
5.3.2.2. Positive Affect

As was the case in Study 2, an adapted version of the 12-Point Affect Circumplex Scale (12-PACS; Yik et al., 2011) was used to measure positive affect, with the adjective format and visual analogue response scale. Focus was again on the Activation-Pleasure and Deactivation-Pleasure quadrants of the circumplex, with scores collapsed to form Activated Positive Affect and Deactivated Positive Affect factors. Internal consistency for the two factors was demonstrated to be good in the present study ($\alpha \geq .72$).

5.3.2.3. Set-Shifting Paradigm

Participants underwent an attentional set-shifting paradigm, adapted from Dreisbach and Goschke (2004), programmed using Matlab R2014. This paradigm has been used in studies to demonstrate the influence of positive affect, as well as monetary incentives, on attentional set-shifting (Liu & Wang, 2014; Muller, Dreisbach, Goschke, et al., 2007). The basic paradigm involves a digit (or letter) categorisation task, in which participants are presented with two digits simultaneously (one above the other) and instructed to categorise a target digit as being odd or even, whilst ignoring a distractor digit. This is based on pre-specified relevant (target) and irrelevant (distractor) colours. Participants undergo a number of pre-switch trials responding to the same target colour and ignoring the same distractor colour, before undergoing a switch and completing a number of post-switch trials.

There are four different switch conditions, two of which are used in Dreisbach and Goschke's (2004) original attention-set shifting paradigm. Figure 5.1 displays these conditions: a perseveration condition (target becomes a new colour and the distractor becomes the pre-switch relevant colour) and a distraction condition (target becomes the pre-switch irrelevant colour and the distractor becomes a new colour). RTs and error rates are measured and switch costs are calculated to allow examination of the costs of changing attentional set for the perseveration and distraction conditions. Figure 5.2 displays the two new switch conditions that have been added to the original paradigm.



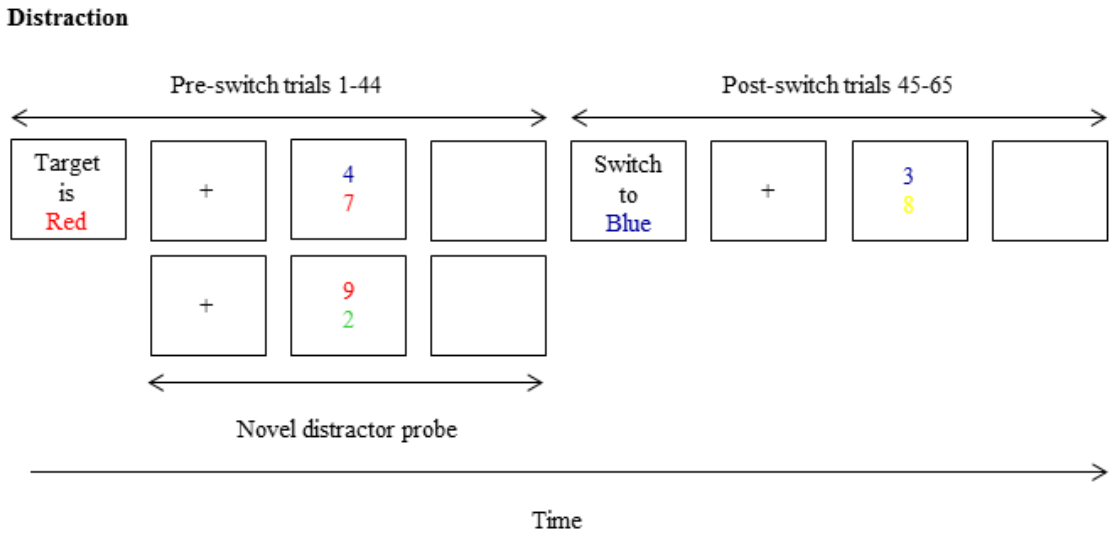


Figure 5.1. *Example sequences from the original set-shifting paradigm for the perseveration and distraction condition. Across both switch conditions, the original set-shifting procedure was adapted to include novel distractor probe trials during the pre-switch trial period. Figure adapted from Liu and Wang (2014).*

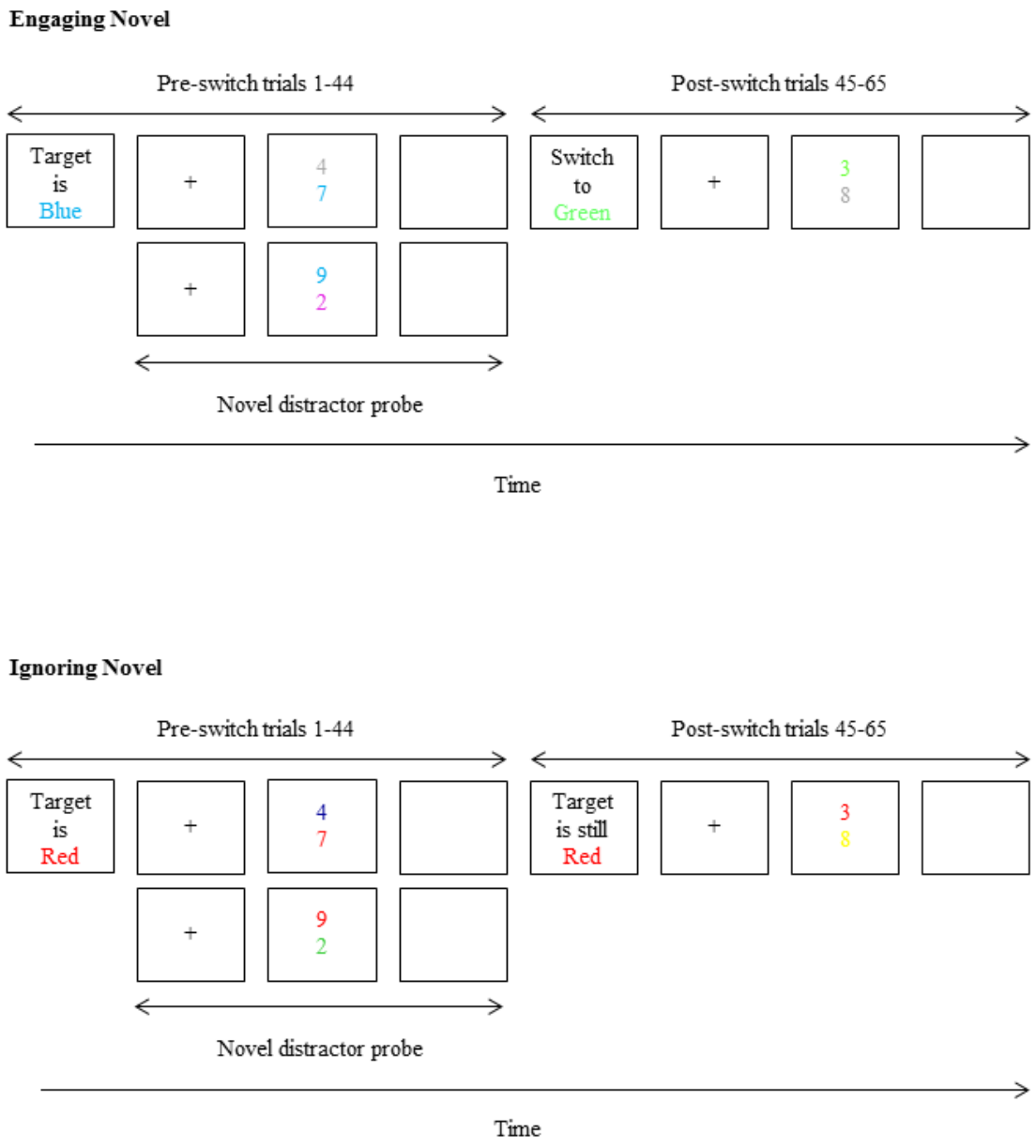


Figure 5.2. *Example sequences from the new blocks added to the set-shifting paradigm for the engaging novel and ignoring novel condition. Across both switch conditions, novel distractor probe trials were included within the pre-switch trial period. Figure adapted from Liu and Wang (2014).*

The first condition, engaging novel, requires switching to a target that is a new colour, whilst the distractor remains unchanged (i.e., the pre-switch irrelevant colour). As a result, switch costs reflect a more accurate measure of engaging a novel target colour, as any costs of disengaging and inhibiting the previously relevant colour in the original perseveration condition are removed. The second condition, ignoring novel, does not require a switch per se

as the target remains the same as the pre-switch relevant colour, whilst the distractor becomes a novel colour. Therefore, switch costs should be a purer reflection of interference due to a novel distractor, as the costs of re-engaging and disinhibiting the previously irrelevant colour are removed.

Digits (2, 3, 4, 5, 6, 7, 8, and 9) were used as stimuli. On each trial, two digits were selected from this set at random for presentation, with target and distractor digits never being the same. Two colour sets were used, one for the perseveration and engaging novel switch conditions (light blue, dark green, purple, and grey) and one set for the distraction and inhibiting novel switch conditions (light green, red, dark blue, and yellow). Assignment of colours within switch condition were fixed for each participant (e.g. red as relevant, blue as irrelevant, yellow as distractor for pre-switch novel probes, and green as novel distractor on post-switch trials), but counterbalanced across participants.

Assignment of digits as targets or distractors and their location (top or bottom of the screen) were determined randomly on each trial for each participant. Participants were required to press a key labelled 'E' for target digits that were even and a key labelled 'O' for target digits that were odd. Digits were response compatible (mapped to the same key, e.g. 2 and 4) or response incompatible (mapped to different keys, e.g. 2 and 3), with the first post-switch trial always being response-incompatible to maximise conflict. As the same digits were never presented as both the target and the distractor, this resulted in 25% more response incompatible compared to compatible trials.

Participants were instructed to respond as quickly and accurately as possible, and prior to completing the task 24 practice trials were completed. These required participants to categorise target digits that were presented alone (in the absence of a distractor stimulus) in all of the colours used in the paradigm, and these appeared in a fixed randomised order across participants. Participant completed all four switch conditions, presented in a counterbalanced order within each mood induction condition. Each block began with instructions indicating the target colour, and these instructions remained on the screen until participants responded.

During pre-switch trials, each trial began with a fixation cross presented for 200 ms, followed by the presentation of the two digits (target and distractor), which remained until participants made a response. A blank screen was then presented for 1000 ms during the inter-trial interval. If an incorrect response was made, the word 'error' was displayed for 1000 ms prior to the blank screen. This extended the inter-trial interval to 2000 ms. Prior to the first post-switch trial

an instruction to switch to a new colour was displayed for 2000 ms. In all other aspects, the procedure and timings were the same for post-switch trials.

Four novel probes were presented during the pre-switch phase in each of the switch conditions, in a fixed randomised order that differed across switch condition. However, novel probes were never presented within the first or last ten trials, and never within four trials of one another.

Switch costs were calculated for perseveration, distraction, engaging novel, and ignoring novel conditions by subtracting pre-switch trials 40-44 from post-switch trials 46-50. RTs for novel probe trials were averaged across blocks and compared to RTs for all other pre-switch trials (the first ten trials of each block and the two trials following novel probes were excluded).

5.3.3. Procedure

Upon arrival participants were seated in the laboratory and completed a paper and pencil version of the 12-PACS. Afterwards, they were seated at a computer to complete practice trials for the set-shifting task, and then had the opportunity to ask any questions before the researcher left the room. Next, participants completed the computerised mood induction, followed by the second version of the 12-PACS, and then two blocks of the set-shifting task. Participants then completed a mood induction booster session and a further two blocks of the set-shifting task. The order of 12-PACS versions was counterbalanced within mood induction conditions and the experiment lasted a total of approximately one hour.

5.4. Results

5.4.1. Data Screening

Data screening used the techniques and followed procedures outlined in the previous chapters. This indicated that all assumptions were met, other than where specified below.

Therefore, data was assumed to be approximately normally distributed for all variables (i.e., a Gaussian distribution was observed on histograms). There were no outliers (i.e., values were not found to be 1.5 interquartile ranges from the median or to have a z-score 3.29 standard deviations above the mean), and there was also approximately equal variance between groups (i.e., Levene's tests were found to be non-significant).

5.4.2. Baseline Comparison of Mood Conditions

To check whether there were any pre-existing individual differences that may have influenced the effect of mood inductions, the differences in positive affect between mood conditions were examined at the pre-induction time point.

Two separate one way (mood condition: neutral/high appetitive/low appetitive) between-subject ANOVAs were conducted with activated and deactivated positive affect as dependent variables. The means for this analysis are displayed in Table 5.1, which demonstrates that there were no significant differences in either activated or deactivated positive affect within mood conditions (F's ≤ 1.35, p's $\geq .266$, $\eta^2p \leq 0.04$).

Table 5.1. *Mean and standard deviations for activated and deactivated positive affect at the pre-induction timepoint for mood conditions.*

	Activated Positive Affect		Deactivated Positive Affect	
	M	*SD*	*M*	*SD*
Neutral	46.74	5.63	58.95	4.29
High Appetitive	40.30	4.33	48.68	3.93
Low Appetitive	46.23	4.48	51.50	5.13

5.4.3. Mood Induction Check

To check the effectiveness of the mood inductions, two separate 2 (time: pre-induction/post-induction) by 3 (mood condition: neutral/low appetitive/high appetitive) mixed design ANOVAs were conducted with activated and deactivated positive affect.

5.4.3.1. Activated Positive Affect

Table 5.2 displays the ANOVA results for activated positive affect, which demonstrates that there were no significant main effects (p's $\geq .430$). However, the pertinent time by mood condition interaction was significant.

Table 5.2. *ANOVA results for differences in activated positive affect depending on time and mood condition.*

Effect	df	*F*	*p*	η^2_p
Time	1, 62	0.63	.430	0.01
Mood Condition	1, 62	0.62	.542	0.02
Time by Mood Condition	2, 62	5.36	.007	0.15

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in activated affect across mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the three multiple comparisons (α = .016), and mean scores are displayed in Figure 5.3.

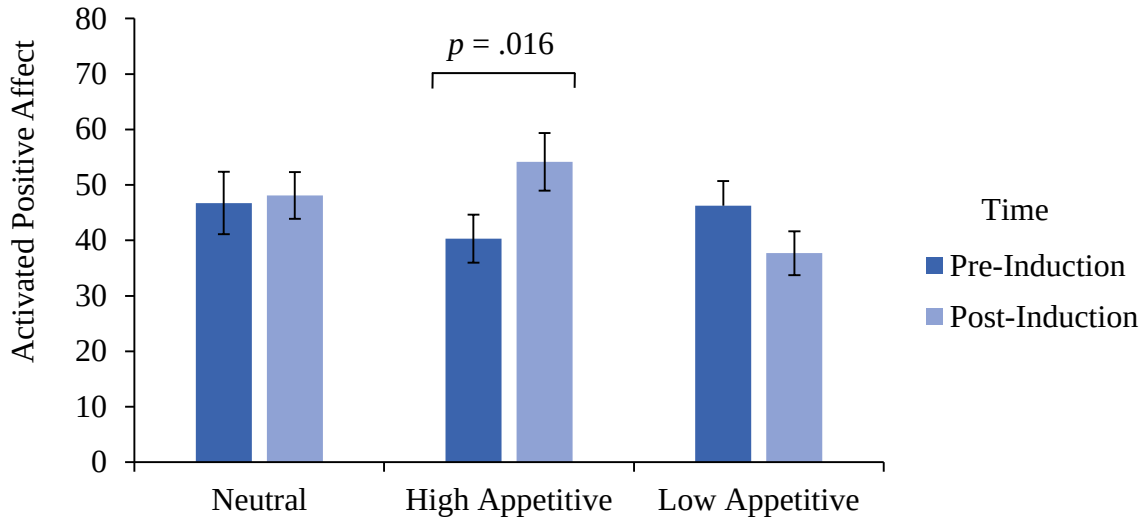


Figure 5.3. *Mood scores for activated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for three multiple comparisons (α = .016).*

Figure 5.3 demonstrates that an increase in activated positive affect approached significance for the high appetitive mood induction [$t(21) = 2.29$, $p = .016$, $d = 0.63$], [($M = 40.30$, $SD = 19.68$) to ($M = 54.18$, $SD = 23.86$)], whilst there was no significant difference for the neutral mood induction [$t(20) = 0.35$, $p = .364$, $d = 0.06$], and a trend towards significance for a decrease for the low appetitive mood induction, [$t(21) = -1.96$, $p = .032$, $d = 0.40$].

Therefore, this suggests that the mood induction was successful in terms of resulting in an increase in activated positive affect only for the high appetitive condition.

5.4.3.2. Deactivated Positive Affect

Table 5.3 displays the ANOVA results for deactivated positive affect, which demonstrates that there was a significant main effect of time and mood condition. However, the pertinent time by mood condition interaction was also significant.

Table 5.3. *ANOVA results for differences in deactivated positive affect depending on time and mood condition.*

Effect	df	*F*	*p*	η^2_p
Time	1, 62	4.24	.044	0.06
Mood Condition	1, 62	3.59	.034	0.10
Time by Mood Condition	2, 62	3.47	.037	0.10

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in activated affect across mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the three multiple comparisons (α = .016), and mean scores are displayed in Figure 5.4.

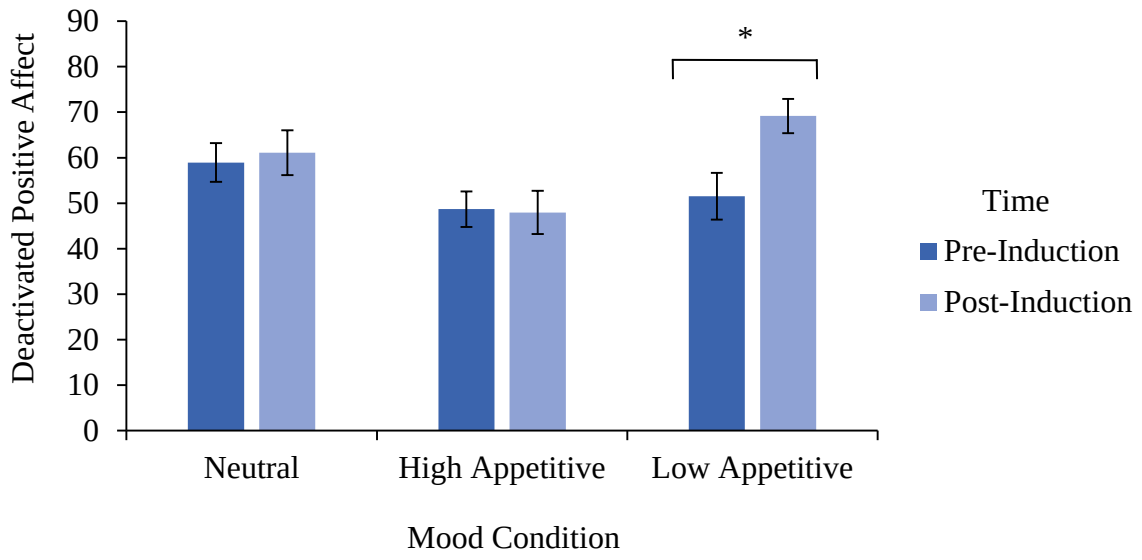


Figure 5.4. *Mood scores for deactivated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for three multiple comparisons * p < .016.*

Figure 5.4 demonstrates a significant increase in deactivated positive affect for the low appetitive mood condition [$t(21) = 3.30$, $p = .002$, $d = 0.83$], [($M = 51.50$, $SD = 24.33$) to ($M = 69.16$, $SD = 17.69$)]. However, there was no significant difference for the neutral mood condition [$t(20) = 0.37$, $p = .357$, $d = 0.10$], or the high appetitive mood condition [$t(21) = -0.15$, $p = .441$, $d = -0.03$].

Again, this suggests that the mood induction was effective in terms of resulting in an increase in deactivated positive affect only for the low appetitive positive mood condition.

5.4.4. Effects of Positive Mood on Set-Shifting

The mean error rate was 4.10% (cf. 4.15%, Dreisbach & Goschke, 2004) and two participants were excluded from analysis as error rate was over three standard deviations above the mean. RTs above 2,000 ms were excluded from analysis.

There were two outliers for pre-switch mean RTs – one high value (slower RT) for the distraction condition (high appetitive mood condition) and one low value (faster RT) for the engaging novel condition (low appetitive condition). There were also three switch cost values determined to be outliers (all in the low appetitive mood condition) – one large value (greater switch cost) in the perseveration condition, and one large and one low value (lower switch cost) in the engaging novel condition. These were winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall pattern of results for this analysis.

5.4.4.1. Perseveration and Distraction

Initially, a 2 (switch condition: perseveration/distraction) by 2 (compatibility: compatible/incompatible) by 3 (mood condition: neutral/high appetitive/low appetitive) mixed ANOVA was conducted with switch costs as the dependent variable. Levene's test was significant for compatible switch costs in the perseveration condition [$F(2,60) = 6.97$, $p = .002$]. However, this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups when cell sizes are equal (Zimmerman, 2004).

There were no significant main effects for switch condition [$F(1,60) = 0.50$, $p = .484$, $\eta^2p = 0.01$], or mood condition [$F(2,60) = 1.60$, $p = .211$, $\eta^2p = 0.05$]. A significant main effect of compatibility approached significance [$F(1,60) = 3.28$, $p = .075$, $\eta^2p = 0.05$], in line with expectations that switch costs would be greater for incompatible ($M = 119.59$, $SD = 153.84$) compared to compatible trials ($M = 74.87$, $SD = 134.16$).

As compatibility did not significantly interact with any other factor (p's $\geq .211$), the following analysis was performed with switch costs collapsed across compatible and incompatible trials, producing overall switch costs for conditions (cf. Dreisbach et al., 2005; Liu & Wang, 2014; Tharp & Pickering, 2011).

To examine the influence of positive mood on the set-shifting paradigm, a 2 (switch condition: perseveration/distraction) by 3 (mood condition: neutral/low appetitive/high appetitive) mixed ANOVA was conducted with switch costs entered as the dependent variable.

The results of this ANOVA are displayed in Table 5.4, which demonstrates no significant main effects ($p \geq .357$), including the pertinent switch by mood condition interaction.

Table 5.4. *ANOVA results for differences in switch costs dependent on switch condition (perseveration vs. distraction) and mood condition*

Effect	df	*F*	*p*	η^2_p
Switch Condition	1, 60	0.05	.831	0.00
Mood Condition	2, 60	1.05	.357	0.04
Switch by Mood Condition	2, 60	0.01	.987	0.00

To confirm that there were no differences in switch costs between the mood conditions, planned contrasts were conducted with independent t-tests. A Bonferroni correction for inflated Type I error due to the four multiple comparisons ($\alpha = .013$), and the means for this analysis are displayed in Figure 5.5.

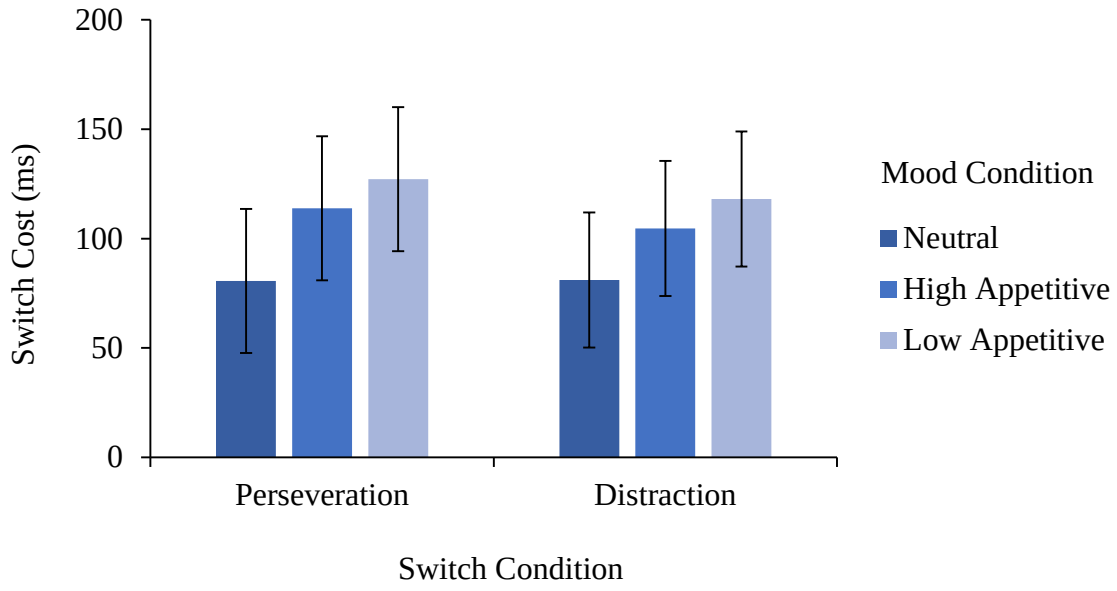


Figure 5.5. *Switch costs for original set-shifting switch conditions for each mood condition. Error bars reflect one standard error above and below the mean.*

Figure 5.5 demonstrates that there was a general pattern towards increased switch costs across both positive mood conditions, compared to the neutral mood condition. However, all contrasts were found not to be significant (p's $\geq .192$).

5.4.4.2. Ignoring Novel and Engaging Novel

A 2 (switch condition: engaging novel/ignoring novel) by 2 (compatibility: compatible/incompatible) by 3 (mood condition: neutral/high appetitive/low appetitive) mixed design ANOVA was conducted with switch costs entered as the dependent variable.

There were no significant main effects for switch condition [$F(1,60) = 1.99$, $p = .164$, $\eta^2p = 0.03$] or mood condition [$F(2,60) = 1.60$, $p = .211$, $\eta^2p = 0.05$]. A significant main effect of compatibility approached significance [$F(1,60) = 3.12$, $p = .082$, $\eta^2p = 0.05$]. This was in line with expectations that switch costs would be greater for incompatible ($M = 132.51$, $SD = 158.49$) compared to compatible trials ($M = 76.77$, $SD = 150.82$).

As compatibility did not significantly interact with any other factor (p's $\geq .170$), the following analysis is performed by collapsing switch costs across compatible and incompatible trials, producing overall switch costs for conditions.

To investigate the effect of positive mood on the set-shifting paradigm, a second 2 (switch condition: engaging novel/ignoring novel) by 3 (mood condition: neutral/low appetitive/high appetitive) mixed ANOVA was conducted, with switch costs entered as the dependent variable. The results of this analysis can be seen in Table 5.5.

Table 5.5. *ANOVA results for differences in switch costs depending on switch condition (engaging novelty vs. ignoring novelty) and mood condition.*

Effect	df	*F*	*p*	η^2_p
Switch Condition	1, 60	1.89	.178	0.03
Mood Condition	2, 60	2.23	.116	0.07
Switch by Mood Condition	2, 60	0.93	.402	0.03

Table 5.5 demonstrates that there were no significant effects (p's $\geq .116$), including the pertinent switch by mood condition interaction.

To confirm that there were no differences in switch costs between the mood conditions, planned contrasts were conducted with independent t-tests. A Bonferroni correction for inflated Type I error due to the four multiple comparisons ($\alpha = .013$), and the means for this analysis are displayed in Figure 5.6.

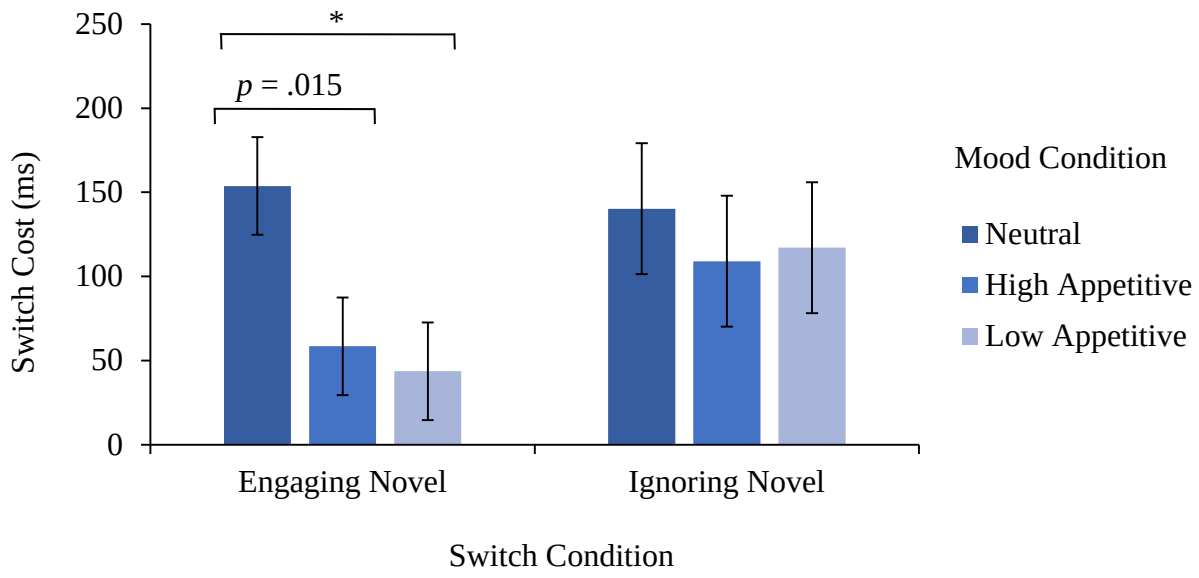


Figure 5.6. *Switch costs for new set-shifting switch conditions for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons * p < .013.*

For the ignoring novel condition, Figure 5.6 confirms that there were no significant differences in switch costs (*p*'s ≥ .290).

However, for the engaging novel condition, Figure 5.6. demonstrates that switch costs were significantly decreased [$t(40) = -2.69$, $p = .006$, $d = -0.83$] for the low appetitive condition ($M = 43.64$, $SD = 125.78$) compared to the neutral condition ($M = 153.76$, $SD = 139.66$). A decrease also approached significance [$t(40) = -2.26$, $p = .015$, $d = -0.69$] for the high appetitive ($M = 58.48$, $SD = 133.89$) compared to the neutral condition.

5.4.4.3. Distractor Compatibility Effects

To see whether mood inductions may have influenced the inhibition of the distractors, distractor compatibility variables were calculated. RTs for pre-switch trials were collapsed across switch conditions, and RTs for compatible trials were subtracted from incompatible trials.

Data was positively skewed, although this should not be problematic for ANOVA analysis, with simulation studies consistently demonstrating that this is robust against even moderate deviations from normality (e.g., Schmider et al., 2010).

A 3 (mood condition: neutral/high appetitive/low appetitive) way between-subjects ANOVA was conducted with the distractor compatibility effect variable entered as the dependent variable.

The means for distractor compatibility effects within mood conditions are displayed in Figure 5.7, and this figure demonstrates that there were no differences in compatibility effects between mood conditions [$F(2,60) = 0.20$, $p = .818$, $\eta^2p = 0.01$].

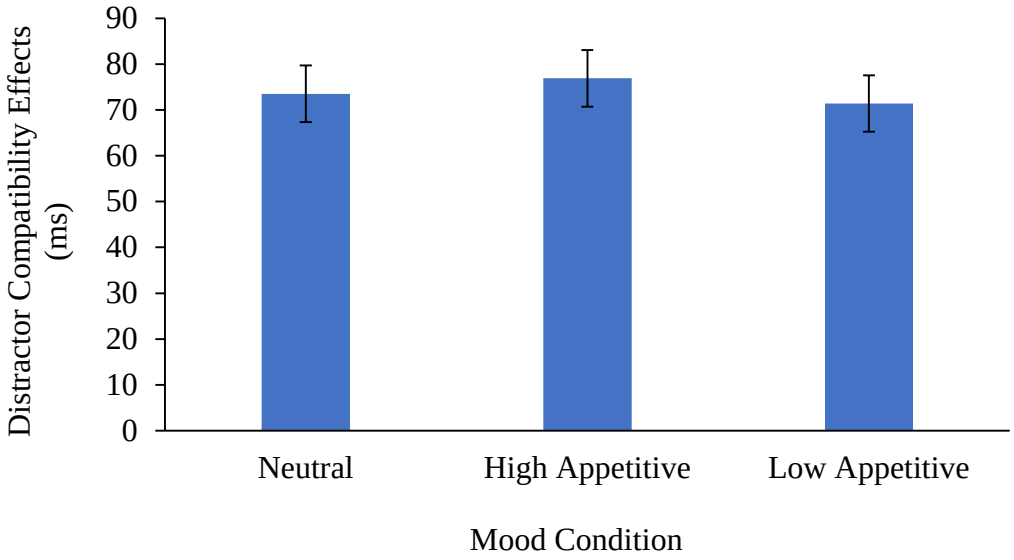


Figure 5.7. *Distractor compatibility effects for each mood condition. Error bars reflect one standard error above and below the mean.*

5.4.4.4. Novel Distractor Probes

A 2 (trial type: novel pre-switch/standard pre-switch trials) by 2 (compatibility: compatible/incompatible) by 3 (mood condition: neutral/high appetitive/low appetitive) mixed design ANOVA was conducted with RTs entered as the dependent variable.

There was a significant main effect of compatibility, $F(1,60) = 5.18$, $p = .026$, $\eta^2p = 0.08$, which was in line with expectations that RTs would be greater for incompatible ($M = 733.41$, $SD = 119.51$) compared to compatible trials ($M = 703.70$, $SD = 125.78$).

As compatibility did not significantly interact with any other factor (p's $\geq .303$), the following analysis was performed by collapsing RTs across compatible and incompatible trials, producing overall RTs for trial types.

To investigate the effect of positive mood on novel distractor probes, a 2 (trial type: novel pre-switch/original pre-switch) by 3 (mood condition: neutral/high appetitive/low appetitive) mixed design ANOVA was conducted with RTs entered as the dependent variable.

The results of this analysis can be seen in Table 5.6, which, as expected, demonstrates that there was a significant main effect of trial type, such that RTs were greater for novel pre-switch trials (*M* = 743.07, *SD* = 136.79) compared to original pre-switch trials (*M* =695.79, *SD* = 100.21), whilst the main effect of mood condition was not significant.

Table 5.6. *ANOVA results for RTs on novel-probe compared to original pre-switch trials depending on mood condition.*

Effect	df	*F*	*p*	η^2_p
Trial Type	1, 60	16.39	< .001	0.22
Mood Condition	2, 60	0.50	.611	0.02
Trial Type by Mood Condition	2, 60	0.30	.745	0.01

However, the pertinent trial type by mood condition interaction was also found not be significant, and the means for this analysis can be seen in Figure 5.8. This suggests that neither type of positive mood influenced RTs on novel distractor probes, suggesting that a possible novelty bias was unaffected by mood in this instance.

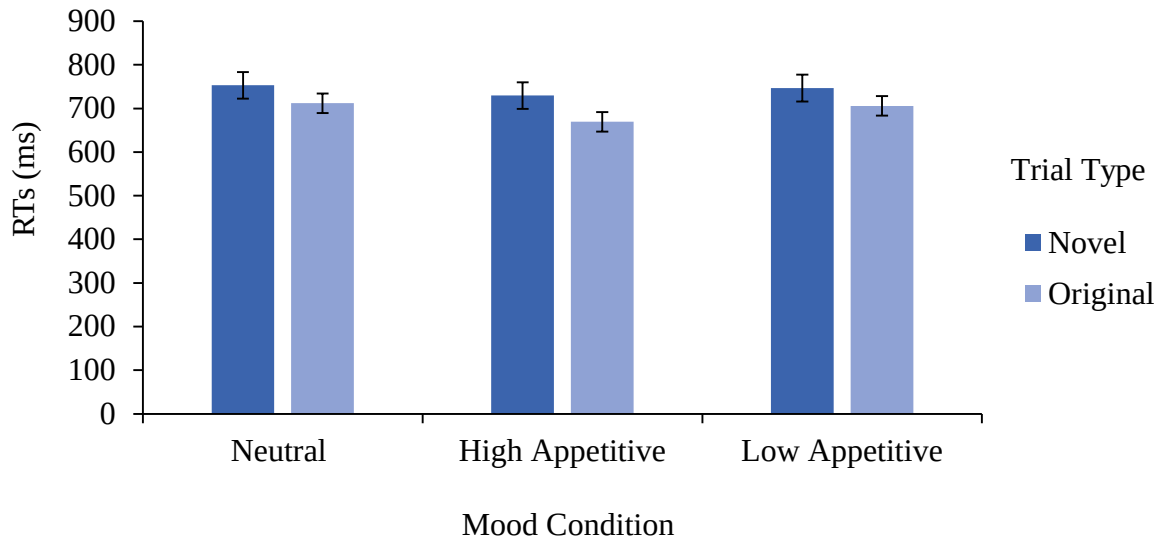


Figure 5.8. *RTs for novel distractor probes compared to original pre-switch trials for each mood condition. Error bars reflect one standard error above and below the mean.*

5.5. Discussion

5.5.1. Positive Mood and Flexibility

The present study aimed to examine the moderating role of appetitive motivation in relation to the influence of positive mood on Dreisbach and Goschke's (2004) attentional set-shifting paradigm. Positive affect has previously been demonstrated to result in lower switch costs in the perseveration condition and greater switch costs in the distraction condition. This indicates that positive affect enhances flexibility in cognitive control, but occurs at the cost of increased distractibility. However, Liu and Wang (2014) demonstrated that the influence of positive affect on this paradigm depends on motivational intensity. Whilst the pattern of results outlined above was found to occur for positive affect that is low in appetitive motivation, positive affect that was high in appetitive motivation was found to result in the opposite pattern of results. This was such that switch costs were greater in the perseveration condition and lower in the distraction condition, which indicates greater stability (attenuated flexibility) and reduced distractibility in cognitive control.

Liu and Wang (2014) manipulated positive affect that was high and low in appetitive motivation using briefly presented images, which may be suggested to induce only transient emotional responses. This was also the case in Dreisbach and Goschke's (2004) study, where briefly presented images were used to induce positive affect. Therefore, the present study aimed to examine performance on the same set-shifting paradigm used in these studies, but in relation to the effect of more enduring mood states. It was hypothesised that the pattern of results observed for positive mood inductions that were high and low in appetitive motivation would be in line with the findings of Liu and Wang (2014). However, no differences in switch costs were observed following either of the positive mood inductions (compared to the neutral induction). This was despite the fact that the inductions were demonstrated to be effective, in terms of producing the affective responses that are associated with positive mood states that are high and low in appetitive motivation (Depue & Collins, 1999).

5.5.1.1. The Motivational Intensity Model

The motivational intensity model of positive affect suggests that appetitive motivation moderates the influence of positive affect on cognition (Gable & Harmon-Jones, 2010). This is primarily based on findings that positive affect that is high and low in appetitive motivation has opposing effects on attentional scope (e.g., Gable & Harmon-Jones, 2008b). However, Liu

and Wang 's (2014) findings suggest that this model can also be applied to the balance between flexibility and stability in cognitive control. In contrast, the null findings observed in the present study suggest that the previously demonstrated influence of positive affect on these processes (and moderation by appetitive motivation) (i.e., Liu & Wang, 2014) may not translate to the more enduring mood states induced in the present study. This is surprising because similar effects have been demonstrated on attentional scope using mood inductions that are similar to those used in the present study (i.e., film clips presented prior to completion of the task) (e.g., Gable & Harmon-Jones, 2008b).

It could be the case that the transient emotional responses induced in previous studies (Dreisbach & Goschke, 2004; Liu & Wang, 2014) may be more able to drive momentary changes in cognitive control processes, as is required on the set-shifting paradigm. Specifically, these studies present affective images briefly prior to each trial, so that positive affect is tightly coupled with the specific task demands (i.e., processing of the stimulus and response). In contrast, the mood inductions in the present study are more temporally remote to the set-shifting paradigm, which may have resulted in null effects observed. However, it could be suggested that these enduring mood states may be more suited to influencing more complex cognitive processes, which may require sustained changes to cognitive control. Specifically, as affect is not coupled with task demands following mood inductions, these states may be more able to drive effects on tasks that require a more general flexible processing “mode”, such as divergent thinking tasks (i.e., as demonstrated in Study 2).

Alternatively, the failure to observe any effects for positive mood on the set-shifting paradigm in the present study could be due to differences in methodological design compared to previous work. Specifically, novel probe trials were introduced into pre-switch blocks across the paradigm, which may have been distracting to participants. This may have resulted in a general slowing of RTs in pre-switch trials, which may have obscured any switch costs. Alternatively, participants may have been more alert to changes to the colour of stimuli, resulting in a general benefit on post-switch RTs. Furthermore, the use of the additional switch conditions may have diluted any effects of positive mood. In addition, whilst the present study used two blocks of each condition, Dreisbach and Goschke (2004) used three. Therefore, this study had more trials from which to calculate switch costs, which may have contributed to observed effects. However, the present study did have a greater number of blocks than Liu and Wang's (2014) study, which demonstrated effects using only one block for each switch condition.

5.5.2. Novelty Bias

Dreisbach and Goschke (2004) argue that the influence of positive affect on the balance between flexibility and stability in cognitive control is driven by a novelty bias, which serves to decrease perseverative attentional focus, at the cost of an increase in distractibility. However, other control processes may have been influenced by positive affect, which could have greater flexibility (and increased distractibility) in the original switch conditions of this paradigm. Therefore, the second aim of the present study was to ascertain with more certainty whether the effect of positive affect in this set-shifting paradigm is indeed driven by a novelty bias. Based on this, two new switch conditions were included within the paradigm: an engaging novel condition and an ignoring novel condition. These aimed to isolate the effects of positive affect, in terms of engaging in the novel target (adapted perseveration condition) and ignoring the novel distractor (adapted distraction condition). It was hypothesised that results would mirror those predicted for the original switch conditions, reflecting the proposition that effects are driven by a novelty bias.

Therefore, positive mood low in appetitive motivation was expected to result in reduced switch costs in the engaging novel condition and increased switch costs in the ignoring novel condition, whilst positive mood high in appetitive motivation was expected to produce the opposite pattern of results. Although no significant effects were found for the ignoring novel condition, both positive mood conditions were found to result in decreased switch costs for the engaging novel condition. This suggests that the influence of positive affect (albeit regardless of motivational intensity) on the original switch conditions, which has been demonstrated in previous studies (e.g., Dreisbach & Goschke, 2004), may indeed reflect an increased novelty bias. This is further supported by the fact that distractor compatibility effects were also examined in the present study, which involved comparing RTs between pre-switch trials that were compatible and incompatible for the different mood conditions. No differences were found between these, which suggests that positive affect had no effect on the inhibition of distractors across the paradigm.

However, the fact that positive mood was found to influence switch costs in the engaging novel condition regardless of motivational intensity is inconsistent with hypotheses. It is also inconsistent with the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect that is high and low in appetitive motivation has opposing effects on cognition. Reduced switch costs in the engaging novel condition as a result of both positive mood inductions in the present study is actually more in line with the reward-as-motivation

hypothesis. In contrast to the motivational intensity model, this hypothesis predicts that all types of positive affect – that are unrelated to task performance – result in reduced effortful control (i.e., greater flexibility) (Goschke & Bolte, 2014). As both mood inductions in the present study were unrelated to task performance, the finding of reduced switch costs in the engaging novel condition for both inductions is in line with the reward-as-motivation hypothesis. Furthermore, across all analyses, generally consistent effects on performance for both positive mood inductions were observed.

5.5.2.1. Reward-as-Motivation Hypothesis

The reward-as-motivation hypothesis suggests that it is rewards (i.e., appetitive goals) that result in greater effortful control (i.e., reduced flexibility) (Aston-Jones & Cohen, 2005). In contrast to the motivational intensity model, this account suggests that it is the active pursuit of rewards, as opposed to the affect that is associated with appetitive motivation, which results in greater stability in cognitive control. The reward-as-motivation hypothesis is supported by the finding that cues to signal the possibility of monetary performance-based incentives result in reduced flexibility (i.e., greater stability) on Dreisbach and Goschke's (2004) set-shifting paradigm (Muller, Dreisbach, Goschke, et al., 2007). However, this finding could also be considered to be in line with the motivational intensity model, as cues for monetary incentives can be assumed to induce positive affect that is high in appetitive motivation. Therefore, an interesting avenue for future research would be to disentangle the effects predicted by the reward-as-motivation hypothesis and the motivational intensity model.

One way to test the predictions of these models would be to examine performance on the set-shifting paradigm for rewards that are and are not dependent upon performance. For example, participants could complete trials, which are preceded by different cues. One block of trials may use cues indicating that monetary rewards are available based on performance. However, another block may use cues indicating that monetary cues will be available regardless of performance. Alternatively, another example would be to have one block of trials that are preceded by cues indicating that monetary cues will be available based on performance. Then, in a further block of trials, these could be preceded by the brief presentation of appetitive images. If necessary, a neutral control condition could also be included, as well as a condition to induce positive affect that is low in appetitive motivation. This would involve adding further blocks of trials, which would be preceded by appropriate images.

Although positive mood (regardless of motivational intensity) was found to influence switch costs in the engaging novel condition, neither of the positive mood inductions had any effect on the ignoring novel condition. It could be the case that any effect of positive mood on switch costs was masked by practice effects, as this was the only condition that required participants to respond to the same colour target on pre- and post-switch trials (i.e., there was no attentional switch). Therefore, this condition may be seen as "easier" than the others, which could have resulted in the novel distractor having less of an effect on performance. However, switch costs were not especially low in this condition, as may have been expected if this was the case (i.e., participants responding faster on post-switch trials due to practice effects). Nevertheless, several novel probe trials were also integrated into pre-switch blocks across conditions, in which the distractor was presented in a novel colour, which provides a further opportunity to examine the effect of positive mood on ignoring novel distractors within this paradigm.

It was hypothesised that positive mood low in appetitive motivation would result in an increase in RTs on novel probe trials, whilst a decrease in RTs was hypothesised to occur for positive mood that was high in appetitive motivation – reflecting an increased and decreased novelty bias respectively. However, no differences in RTs were observed for either positive mood condition, which supports the null findings observed in the ignoring novel condition. One explanation for a lack of effects here could be that a novelty bias is only relevant when changes in attentional set are required. Neither the ignoring novel switch condition nor the novel probe trials require a switch in attentional set, as these continued to use the same colour target for pre- and post-switch targets. However, the original switch conditions and the engaging novel condition all require changes to attentional set, which may provide a greater opportunity for an attentional (i.e., novelty) bias to be observed. Therefore, this may explain the null findings, as the ignoring novel condition and novel probe trials may require relatively less cognitive control.

Finally, this study has provided some support for an increased novelty bias as underlying the effect of positive affect on cognitive control (i.e., resulting in greater flexibility and an increase in distractibility). However, it is not clear whether an increased novelty bias drives this effect (i.e., as is suggested by Dreisbach & Goschke, 2004), or whether greater flexibility in cognitive control results in an increased novelty bias. Therefore, establishing the direction of this effect would be an interesting avenue for future research. One way to do this would be to examine whether a novelty bias is affected by changes in the balance between flexibility and stability in cognitive control. This could be achieved using the Stroop paradigm, as stability has been

demonstrated to be increased (i.e., flexibility is reduced) on trials following increased conflict (Egner, 2007). If a reduced novelty bias is driving this effect, attention should be less likely to be captured by a novel stimulus included on the following trial. Therefore, RTs can be measured for these trials and compared between typical trials and trials that follow those with increased conflict.

5.5.3. Conclusions

To conclude, when using a mood induction procedure, positive affect was not found to influence the original perseveration and distraction switch conditions of Dreisbach and Goschke's (2004) set-shifting paradigm. This suggests that previous findings that positive affect induced as transient emotional responses results in greater flexibility (and increased distractibility) may not extend to more enduring positive mood states. It could be the case that transient emotional responses that are tightly coupled to the specific demands of the set-shifting task may be more suited to facilitating the momentary changes in cognitive control processes that are required in this task. In contrast, the more enduring mood states elicited by inductions in the present study are more temporally remote to task demands, which may explain the null results. It is suggested that these states may be more suited to facilitating changes in tasks assessing more complex cognitive processes (e.g., divergent thinking), which require a less specific flexible “mode” of processing. However, null results for the influence of mood inductions on the set-shifting paradigm may also have been due methodological differences (i.e., inclusion of novel probe trials or additional switch conditions) compared to previous studies.

Despite null results on the original set-shifting conditions, positive mood was found to reduce switch costs in the new engaging novel condition, which isolated aspects of processing relating to an increased novelty bias in the original perseveration condition. This supports Dreisbach and Goschke's (2004) suggestion that positive affect may enhance flexibility in cognitive control by increasing a bias toward novelty. Although positive affect was found to influence performance on the engaging novel condition, this was not found to be moderated by appetitive motivation, which is not in line with the motivational intensity model (Gable & Harmon-Jones, 2010). Instead, this finding is more in line with the reward-as-motivation hypothesis (Goschke & Bolte, 2014), which proposes that all types of positive affect that are unrelated to task performance have a similar effect on cognitive control (i.e., result in greater flexibility). However, no effect of positive mood was found on the ignoring novel or novel probe trials,

which isolated aspects of processing relating to a novelty bias in the original distraction condition. It was suggested that these null results may reflect the possibility that positive affect results in a novelty bias only when a change in attentional set is required.

6. Study 4 – Positive mood and flexibility in set-shifting: Moderation by appetitive motivation and relationship to EBR

6.1. Abstract

Study 3 aimed to examine the influence of positive mood states that were high and low in appetitive motivation on Dreisbach and Goschke's (2004) attentional set-shifting paradigm, which assesses flexibility, in terms of perseveration and distractibility. However, no effect of mood was found, which may have been due to adaptations made to this paradigm to address additional aims in this study. Therefore, Study 4 aimed to re-examine the influence of positive mood on attentional set-shifting, without adapting the set-shifting paradigm. An additional aim was to examine the influence of positive mood states on EBR, and the relationship between EBR and set-shifting. This was based on findings that a greater baseline EBR is associated with greater flexibility (i.e., reduced perseveration and increased distractibility on this paradigm (e.g., Dreisbach et al., 2005).

Forty-four participants took part in a laboratory-based experimental study and were randomly assigned to a high or low appetitive condition. Participants completed a neutral and a positive mood induction in separate experimental sessions, which used the same stimuli as Studies 1, 2, and 3. The 12-PACS (Yik et al., 2011) was used to measure positive affect at pre- and post-induction timepoints, and EEG (recorded and analysed as part of Study 6) was used to measure EBR during the induction. Following inductions, participants completed the attentional set-shifting task. This involved categorising a target stimulus, which was presented simultaneously with a distractor stimulus. Blocks of trials assessed perseveration and distractibility.

ANOVAs demonstrated that mood inductions were effective, and that there was a general non-significant pattern of greater flexibility (reduced perseveration and increased distraction) for the low appetitive induction, in line with the motivational intensity model (Gable & Harmon-Jones, 2010). It may be the case that effects are weaker for enduring mood states compared to transient emotional responses that were induced in previous studies (e.g., Liu & Wang, 2014). In contrast, a general detrimental effect of positive mood approached significance for the high appetitive induction, which is not in line with the motivational intensity model as it reflects increased stability. EBR was found to be increased for the high appetitive induction (in line with Study 2), but no correlations were found between EBR and perseveration or distractibility.

6.2. Introduction

6.2.1. Positive Affect and Flexibility

Study 3 examined whether appetitive motivation moderated the influence of positive mood on more fundamental and basic cognitive processes (e.g., balance between flexibility and stability in cognitive control), as opposed to the more complex cognitive processes assessed in Studies 1 and 2 (i.e., divergent and convergent thinking in creativity). This was based on previous findings indicating that positive affect may influence performance on an attentional set-shifting paradigm, which was designed to assess that balance between flexibility and stability in cognitive control (Dreisbach & Goschke, 2004). Within this paradigm, participants categorised targets, whilst ignoring distractors, which were specified by relevant and irrelevant colours. Two switch conditions involved participants being instructed to respond to different coloured stimuli. In a perseveration condition, focus was switched to a novel colour target, whilst the distractor became the previously relevant colour. However, in a distraction condition, focus was switched to a target that was the previously irrelevant colour, whilst the distractor became a novel colour.

Positive affect was found to result in greater flexibility (at the cost of increased distractibility) on this paradigm. This was suggested to be due to an increased novelty bias because: i) switch costs were decreased in the perseveration condition (i.e., attention is captured by the novel post-switch target and perseveration of the previous target, now the post-switch distractor, is reduced); and ii) switch costs were increased in the distraction condition (i.e., attention is captured by the novel post-switch distractor, resulting in increased distractibility). However, a subsequent study, conducted by Liu and Wang (2014), demonstrated that the influence of positive affect on this set-shifting paradigm was moderated by motivational intensity. This was such that, positive affect low in appetitive motivation replicated Dreisbach and Goschke's (2004) original findings, whilst positive affect that was high in appetitive motivation produced the opposite pattern of results (i.e., switch costs were increased in the perseveration condition, but decreased in the distraction condition).

Therefore, Liu and Wang's (2014) findings suggest that it is specifically positive affect that is low in appetitive motivation that results in greater flexibility in cognitive control, whilst positive affect that is high in appetitive motivation results in attenuated flexibility (i.e., greater stability). However, this study, and the original work conducted by Dreisbach and Goschke (2004), manipulated affect using images that were briefly presented prior to each trial on the

set-shifting paradigm. As this may have only induced transient emotional responses, Study 3 aimed to examine whether previous findings could be extended to more enduring mood states (i.e., whether appetitive motivation moderates the influence of positive mood on the balance between flexibility and stability in cognitive control). To do this, the effect of positive mood inductions that were high and low in appetitive motivation were examined in relation to performance on the set-shifting paradigm (in comparison to a neutral mood induction). However, neither of the positive mood inductions were found to influence performance, on either the perseveration or distraction switch condition.

6.2.2. Issues with Design

These null results may indicate that Liu and Wang's (2014) findings cannot be extended to more enduring mood states. However, an alternative explanation may be that the null results of Study 3 were due to methodological differences, when compared to the methodologies of previous work. Although Study 3 was intentionally designed to replicate the design of previous studies (e.g., Dreisbach & Goschke, 2004) as closely as possible, it was necessary to make some adaptions due to the additional aims of this study. Specifically, Study 3 not only aimed to examine the effect of more enduring positive mood states on the set-shifting paradigm, but it also aimed to further explore the suggestion that a novelty bias underlies previously demonstrated effects. To do this, two new switching conditions were added to the paradigm, and novel probe trials were presented in the pre-switch trials during each switch condition block. Therefore, it may have been the case that these adaptions (particularly the pre-switch novel probe trials) were distracting for participants, or may have resulted in participants becoming more alert to possible changes in the colour of stimuli.

The adaptions that were made to the methodology of Study 3 may have masked any possible effects of positive mood on the set-shifting paradigm. Due to this possibility, the present study will again aim to assess whether appetitive motivation moderates the influence of positive mood on the balance between flexibility and stability in cognitive control, using the same set-shifting paradigm. This will provide a further opportunity to examine whether Liu and Wang's (2014) findings (i.e., opposite effects for positive affect that is high and low in appetitive motivation on this paradigm), which were observed by inducing transient emotional responses, can be extended to more enduring positive mood states. However, based on the possible methodological limitations of Study 3, the aims and methodology of the present study will be simplified, so that only the effect of positive mood on the original perseveration and distraction

switch conditions will be examined. Therefore, this study will not include the new switch conditions and novel probe trials that were included in Study 3 to explore the possibility of a novelty bias as an underlying mechanism.

6.2.3. Motivational Intensity Model

As outlined in Study 3, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognition is moderated by appetitive motivation. Specifically, positive affect low in appetitive motivation is argued to result in broader cognition, whilst positive affect high in appetitive motivation is argued to result in narrower cognition. This model was originally based on studies examining attentional scope, but, given Liu and Wang's (2014) findings, has been expanded to include the trade-off between flexibility and stability in cognitive control. Alternatively, the reward-as-motivation hypothesis (Goschke & Bolte, 2014) suggests that potential rewards (or appetitive goals) increase motivation to engage in effortful control (i.e., reduced flexibility/greater stability) to optimise task performance (Aston-Jones & Cohen, 2005). This is supported by findings of attenuated flexibility on Dreisbach and Goschke's (2004) set-shifting paradigm when trials were proceeded by cues indicating performance-based monetary reward incentives were available (Muller, Dreisbach, Goschke, et al., 2007).

6.2.4. Reward-as-Motivation Hypothesis

The reward-as-motivation hypothesis also suggests that positive affect that is unrelated to task performance results in a more flexible and exploratory processing mode (Carver, 2003). Although this account has recently suggested that this effect may be especially apparent for positive affect that is low in appetitive motivation (Goschke & Bolte, 2014), no clear distinction is made for the effect of positive affect on cognitive control based on motivational intensity (cf., the motivational intensity model, Gable & Harmon-Jones, 2010). Therefore, the reward-as-motivation hypothesis cannot account for the findings of Liu and Wang (2014). However, it could be the case that the brief presentation of images prior to trials on the set-shifting paradigm may mimic the effect of performance-dependent reward. This could be because the affective images were tightly coupled with the task demands (i.e., prior to attentional processing and response), compared to the separate more enduring mood inductions that were used in Study 3 (see Section 5.2.5 for a more detailed discussion).

6.2.5. Neurobiological Mechanisms

Durstewitz and Seamans (2008) propose a dual-state model of the prefrontal cortex, such that states dominated by different types of dopamine receptor neuron activity have different effects on cognitive control. Specifically, a state dominated by tonic D1 activity is proposed to promote the stabilisation of representations in working memory. However, a state dominated by phasic D2 activity is suggested to promote fast and flexible switching between representations. The reward-as-motivation hypothesis suggests that incentives result in an increase in tonic D1 dopamine activity in the prefrontal cortex (Braver, 2012), resulting in reduced flexibility on Dreisbach and Goschke's (2004) set-shifting paradigm (Muller, Dreisbach, Goschke, et al., 2007). Specifically, novel stimuli, proposedly causing phasic D2 activity, may be less able to trigger updating and a shift in attentional focus when tonic D1 activity in the prefrontal cortex is heightened. Therefore, switch costs would be increased in the perseveration condition (i.e., novel target), but decreased in the distraction condition (i.e., novel distractor), reflecting reduced flexibility in cognitive control.

Frank and O'Reilly (2006) suggest that the flexibility in cognitive control depends on dopamine activity in the basal ganglia. Specifically, an increase in dopamine activity is proposed to activate D1 receptor neurons, which excites a phasic "Go" pathway, facilitating updating by disinhibiting the flow of information into working memory. This is suggested to be complimented by the suppression of tonic D2 receptor neurons, which inhibits a "NoGo" pathway that prevents information flow into working memory. Based on this, positive affect may be proposed to inhibit the tonic activity of a "NoGo" pathway in the basal ganglia (i.e., phasic D1 activity), resulting in novel stimuli being more likely to trigger the updating of representations in working memory and a shift in attention towards these. Therefore, this activity would be beneficial in the perseveration condition of the set-shifting paradigm (i.e., novel target), but detrimental in the distraction condition (i.e., novel distractor), which is in line with findings from Dreisbach and Goschke (2004).

Although no specific neurobiological mechanisms are provided by the motivational intensity model (Gable & Harmon-Jones, 2010), Depue and Collins (1999) suggest that positive affect high in appetitive motivation is related to an increase in dopamine activity in the prefrontal cortex. However, positive affect low in appetitive motivation is proposed to be related to separate neural substrates (Berridge & Robinson, 1998). Therefore, it may be suggested that it is not only reward incentives that result in an increase in the activity of D1 neurons in the prefrontal cortex (i.e., facilitating greater stability/reduced flexibility in cognitive control), but

that this may also occur for positive affect high in appetitive motivation (i.e., in the absence of active pursuit of reward/goals). This would be in line with the findings of Liu and Wang (2014), which demonstrated that the previous effects observed on the set-shifting paradigm for reward incentives (i.e., Muller, Dreisbach, Goschke, et al., 2007) and (putatively low-appetitive) positive affect (i.e., Dreisbach & Goschke, 2004) were mirrored by positive affect that was high compared to low in appetitive motivation.

The suggestion that dopamine activity may underlie the effect of positive affect on the balance between flexibility and stability in cognitive control has been investigated by examining performance on Dreisbach and Goschke's (2004) set-shifting paradigm in relation to baseline EBR. This is suggested to reflect dopamine activity, and primarily D2 dopamine receptor activity in the basal ganglia, when this is assessed at baseline (Jongkees & Colzato, 2016). In three separate studies, individuals with greater EBR were demonstrated to display greater flexibility on the set-shifting paradigm (Dreisbach & Goschke, 2004; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011). This was such that switch costs were found to be increased in the perseveration condition, but reduced in the distraction condition (compared to individuals with a lower EBR). Therefore, this supports the suggestion that positive affect may result in greater flexibility in cognitive control, due to an increase in D2 activity in the basal ganglia. However, this has not been directly examined in relation to the influence of positive affect on this set-shifting paradigm.

As outlined in Studies 1 and 2, Chermahini and Hommel (2012) found that the relationship between baseline EBR and performance on a creativity task requiring flexibility (i.e., divergent thinking) followed an inverted U-shape. Furthermore, a positive mood induction was found to result in an increase in EBR, but greater flexibility was found to occur only for those individuals with a lower baseline EBR (i.e., reflecting the inverted U-shaped relationship at baseline). This suggests that positive mood does result in greater flexibility, but this is dependent on individual differences in dopamine activity and, more specifically, this likely reflects D2 activity in the basal ganglia. As stated above, although Dreisbach et al. (2005) demonstrated that baseline EBR was related to greater flexibility on the set-shifting task, this has yet to be examined in relation to: i) the influence of positive mood states on performance in this task; and ii) when taking into account the motivational intensity of inductions.

6.2.6. Present Study

To recap, the first aim of the present study is to examine whether appetitive motivation moderates the influence of positive mood on the balance between flexibility and stability in cognitive control. To do this, Study 3 will be replicated, such that performance on Dreisbach and Goschke's (2004) set-shifting paradigm will be examined following positive mood inductions that are either high or low in appetitive motivation (compared to a neutral mood induction). However, as the addition of new switch conditions in Study 3 may have masked the effects of positive mood on this paradigm, the focus in the present study will be on the original perseveration and distraction switch conditions only. This will allow examination of whether Liu and Wang's (2014) previous findings (i.e., greater flexibility for positive affect low in appetitive motivation, but reduced flexibility for positive affect that is high in appetitive motivation), which were demonstrated by inducing transient emotional responses, can be extended to more enduring mood states.

In line with the motivational intensity model (Gable & Harmon-Jones, 2010), and previous findings (i.e., Liu & Wang, 2014), but contradictory to the reward-as-motivation hypothesis (Goschke & Bolte, 2014), it is expected that appetitive motivation will moderate the effect of positive mood on the set-shifting paradigm. It is hypothesised that positive mood that is low in appetitive motivation will enhance flexibility (at the cost of increased distractibility), which will be demonstrated by an increase in switch costs in the perseveration condition, but a decrease in switch costs in the distraction condition. As the opposite pattern of results is expected for positive mood that is high in appetitive motivation, it is also hypothesised that positive mood that is high in appetitive motivation will result in reduced flexibility (and decreased distractibility). Therefore, it is expected that there will be an increase in switch costs in the perseveration condition, but a decrease in switch costs in the distraction condition. These results would be in line with the motivational intensity model and replicate previous findings (Liu & Wang, 2014).

A second aim of the present study is to explore the neurobiological mechanisms underlying the effect of these positive mood states on cognitive control. This is based on literature suggesting that positive affect that is high vs. low in appetitive motivation is related to separate neural substrates (Berridge & Robinson, 1998). Positive affect that is high in appetitive motivation is suggested to be related to an increase in dopamine activity in the prefrontal cortex (Depue & Collins, 1999). However, Chermahini and Hommel (2012) have demonstrated that positive affect (presumably low in appetitive motivation) was related to an increase in EBR, which the

authors suggested reflects an increase in dopamine activity in the basal ganglia. However, Study 2 found that EBR was increased following only the positive mood induction that was high in appetitive motivation, and that the positive mood induction that was low in appetitive motivation resulted in a decrease in EBR. This is not in line with the findings of Chermahini and Hommel (2012), although it is in line with a reciprocal relationship between dopamine activity in the prefrontal cortex and basal ganglia (Cools & D'Esposito, 2011).

EBR will be assessed in the present study during both positive mood inductions that are high and low in appetitive motivation, and this will be compared to the neutral induction. It is unclear why only the positive mood induction high in appetitive motivation resulted in an increase in EBR in Study 2, as EBR has previously been found to increase as a result of pharmacological manipulations that target D1, as well as, D2 dopamine activity (i.e., predominantly found in the prefrontal cortex and the basal ganglia respectively, Elsworth et al., 1991). Therefore, an increase in EBR for only the positive mood induction high in appetitive motivation suggests that this may be reflecting an increase in D1 activity in the prefrontal cortex. As an increase in EBR was not observed for the positive mood induction low in appetitive motivation, this does not provide any evidence that EBR may also be reflecting an increase in D2 activity in the basal ganglia. Based on this, an exploratory approach will be taken to examine the effect of positive mood inductions on EBR in the present study.

However, EBR at baseline has been suggested to primarily reflect D2 dopamine activity in the basal ganglia (Jongkees & Colzato, 2016). This in line with the inverted U-shaped relationship found between flexibility in divergent thinking and EBR at baseline by Chermahini and Hommel (2010), as well as findings that individuals with a higher EBR demonstrate greater flexibility on Dreisbach and Goschke's (2004) set-shifting paradigm (Dreisbach et al., 2005). However, there was no evidence of an inverted U-shaped relationship between flexibility in divergent thinking and EBR in a neutral induction of Study 2, possibly indicating that baseline EBR reflected dopamine activity in the prefrontal cortex. Therefore, an exploratory approach will be taken to examine the relationship between EBR and switch costs on the set-shifting paradigm in the neutral induction in the present study. An exploratory approach will also be taken to examine the moderating role of neutral EBR on switch costs in, as well as the moderating role of neutral EBR in relation to the influence of positive mood (i.e., high vs. low in appetitive motivation) on switch costs.

6.2.7. Aims and Hypotheses

1. To examine whether appetitive motivation moderates the influence of positive mood on the balance between flexibility and stability in cognitive control.

i) It is hypothesised that positive mood that is low in appetitive motivation will enhance flexibility (at the cost of increased distractibility), which will be demonstrated by an increase in switch costs in the perseveration condition, but a decrease in switch costs in the distraction condition.

ii) It is also hypothesised that positive mood that is high in appetitive motivation will result in reduced flexibility (and decreased distractibility). Therefore, it is expected that there will be an increase in switch costs in the perseveration condition, but a decrease in switch costs in the distraction condition.

2. To explore the neurobiological mechanisms underlying the effect of these positive mood states on cognitive control.

i) An exploratory approach will be taken to examine the effect of positive mood inductions on EBR.

ii) An exploratory approach will be taken to examine the relationship between EBR and switch costs on the set-shifting paradigm for the neutral induction.

iii) An exploratory approach will also be taken to examine the moderating role of EBR for the neutral induction in relation to the influence of positive mood states (i.e., that are high and low in appetitive motivation) on switch costs in the perseveration and distraction conditions.

6.3. Method

6.3.1. Participants

Forty-four participants (11 males, 31 females) aged between 18 and 64 years (M = 36.83 years, SD = 12.95) were recruited using advertisements at a London university, and received £10 in compensation for their time. Participants were randomly assigned to either a positive mood condition high in appetitive motivation (n = 22) or a positive mood condition low in appetitive motivation (n = 22). However, one participant did not return for the second experimental session, reducing total sample size to N = 43 for within-subjects comparisons, and n = 21 in the appetitive condition. No participants had any problems with their colour vision. The study

was approved by the University Research Ethics Committee, and all participants provided informed consent at the start of the study, and were fully debriefed at the end of the study.

6.3.2. Measures

6.3.2.1. Mood Induction

All participants completed a neutral mood induction and a positive mood induction that was either high or low in appetitive motivation. The vignettes, music, instructions, and procedure were the same as those in Studies 2 and 3. A booster mood induction was also used part way through the experimental session, which was the same at that used in Study 3.

6.3.2.2. Positive Affect

As was the case in Studies 2 and 3, an adapted version of the 12-Point Affect Circumplex Scale (12-PACS; Yik et al., 2011) was used to measure positive affect, with the adjective format and visual analogue response scale. Focus was again on the Activation-Pleasure and Deactivation-Pleasure quadrants of the circumplex, with scores collapsed to form Activated Positive Affect and Deactivated Positive Affect factors. Internal consistency for the two factors was demonstrated to be good in the present study ($\alpha \geq .61$).

6.3.2.3. Set-Shifting Paradigm

Participants underwent the same attentional set-shifting paradigm used in Study 3, which was adapted from Dreisbach and Goschke (2004). However, only the original perseveration (target becomes a new colour and the distractor becomes the pre-switch relevant colour) and distraction (target becomes the pre-switch irrelevant colour and the distractor becomes a new colour) switch conditions were included. Unlike Study 3, there were also no novel probes included on pre-switch trials.

Digits (2, 3, 4, 5, 6, 7, 8, and 9) and letters (A, E, O, U, K, M, R, and S) were used as stimuli. Participants completed blocks of each switch condition using either digits or letters, and the order of these was counterbalanced within mood conditions. On each trial, two digits/letters were selected from these sets at random for presentation, with target and distractors never being the same. Two colour sets were used, one for digits (red, blue, and yellow) and one for letters (green, pink, and grey). Assignment of colours within switch conditions was fixed for each

participant (e.g. red as relevant, blue as irrelevant, and yellow as novel colour on post-switch trials), but counterbalanced across participants. The assignment of digits/letters as targets or distractors and their location (top or bottom of the screen) was determined randomly on each trial. To respond, participants were required to press a key labelled 'E/V' for target digits that were even and for letters that were vowels, and a key labelled 'O/C' for target digits that were odd and for letters that were consonants. Trials could each be response compatible (mapped to the same key, e.g. 2 and 4, or A and E) or response incompatible (mapped to different keys, e.g. 2 and 3, or A and K), with the first post-switch trial always being response-incompatible to maximise conflict. The same digits/letters were never presented as both the target and the distractor, which resulted in 25% more response incompatible compared to compatible trials.

Participants were instructed to respond as quickly and accurately as possible, and prior to completing the main task 32 practice trials (16 for digits and 16 for letters) were completed. These required participants to categorise target digits and letters presented alone (in the absence of a distractor stimulus) in all of the colours used in the paradigm. Stimuli in practice trials appeared in a fixed randomised order across participants. Each experimental block began with instructions indicating the target colour, and these instructions remained on the screen until participants responded. The timings of trials were the same as Study 3, such that pre-switch trials began with a fixation cross (200ms), followed by the presentation of the two digits (target and distractor), which remained until participants made a response. A blank screen was then presented (1000ms) during the inter-trial interval, but if an incorrect response was made, the word 'error' was displayed (1000ms) prior to the blank screen (extending the inter-trial interval to 2000ms). Prior to the first post-switch trial an instruction to switch to a different colour was displayed (2000ms), but in all other aspects, the procedure and timings were the same for post-switch trials.

Participants completed a total of 65 trials in each block (45 pre-switch and 20 post-switch). RTs and error rates were measured and switch costs were calculated separately for perseveration and distraction conditions by subtracting pre-switch trials 40-44 from post-switch trials 46-50. This allowed examination of the costs of changing attentional set within each of the conditions.

6.3.2.4. EBR

EEG recordings during the mood induction period were visually examined for spontaneous eye blinks. The low-pass filter was reduced to 15 Hz, in order to remove high frequency activity

that may distract from blinks (Nakanishi et al., 2012). Visual determination of eye blinks was based on sharp increases in the amplitude of the waveform (greater than 100 μV) occurring for less than 500 ms, and high amplitude increases consistent with horizontal eye movements were not counted as blinks (Barbato et al., 2012; Byrne et al., 2015). The first minute was considered to be a period of adaptation and was not included in analysis (Borges et al., 2010). The following 4min were divided into 60sec periods, and the mean number of eye blinks were calculated (c.f. Dreisbach et al., 2005). Inter-reliability for the determination of eye blinks from EEG recordings was found to be good ($r = .97$, $p < .001$) for a randomly selected 10% sample of the data.

6.3.3. Procedure

Before the procedure is outlined, it is important to note that Study 6 (presented in Chapter 8 of this thesis) examines the influence of positive mood states on frontal activity in the brain. The data that is presented in that chapter was collected simultaneously with the present study, using an EEG methodology. This will be addressed in much greater depth in the methodology (and results presented) in Study 6, but it is referred to below as part of the procedure for the present study.

When arriving at the laboratory, the researcher initially prepared the participant for EEG recording. Afterwards, participants completed a paper version of the 12-PACS, and had the opportunity to ask any questions before the researcher left the room. Next, participants completed the computerised mood induction (whilst EEG was recorded) and then completed the second version of the 12-PACS. Following this, participants completed the set-shifting task, which included a mood booster session after the first two blocks.

Participants completed two laboratory-based sessions, at the same time of day separated by one week. The same procedure was followed in both sessions, with the only difference being the mood induction – in one session participants would complete a positive induction and in the other session they would complete the neutral induction. The order of mood induction conditions was counterbalanced across participants, and the order of the 12-PACS versions was counterbalanced within mood induction conditions (but remaining constant for a participant across experimental sessions). Each experimental session lasted approximately 1 hour.

6.4. Results

6.4.1. Data Screening

Data screening used the techniques and followed procedures outlined in the previous chapters. This indicated that all assumptions were met, other than where specified below.

Therefore, data was assumed to be approximately normally distributed for all variables (i.e., a Gaussian distribution was observed on histograms). There were no outliers (i.e., values were not found to be 1.5 interquartile ranges from the median or to have a z-score 3.29 standard deviations above the mean), and there was also approximately equal variance between groups (i.e., Levene's tests were found to be non-significant).

6.4.2. Mood Induction Check

To examine the effectiveness of the mood induction, two separate 2 (time: pre-induction/post-induction) by 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVAs were conducted with activated and deactivated positive affect as dependent variables.

6.4.2.1. Activated Positive Affect

The ANOVA results for activated positive affect are displayed in Table 6.1, which demonstrates that all main effects were significant, other than for mood condition. This table also demonstrates that interaction effects were also all significant, including the pertinent time by induction by mood condition interaction.

Table 6.1. *ANOVA results for differences in activated positive affect depending on time, induction, and mood condition.*

Effect	df	*F*	*p*	η^2_p
Time	1, 41	11.60	.001	0.22
Induction	1, 41	10.85	.002	0.21
Mood Condition	1, 41	2.76	.104	0.06
Time by Induction	1, 41	16.78	< .001	0.23
Time by Mood Condition	1, 41	10.29	.003	0.20
Time by Induction by Mood Condition	1, 41	16.78	< .001	0.29

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in activated positive affect. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons (α = .013). Mean scores are displayed in Figure 6.1.

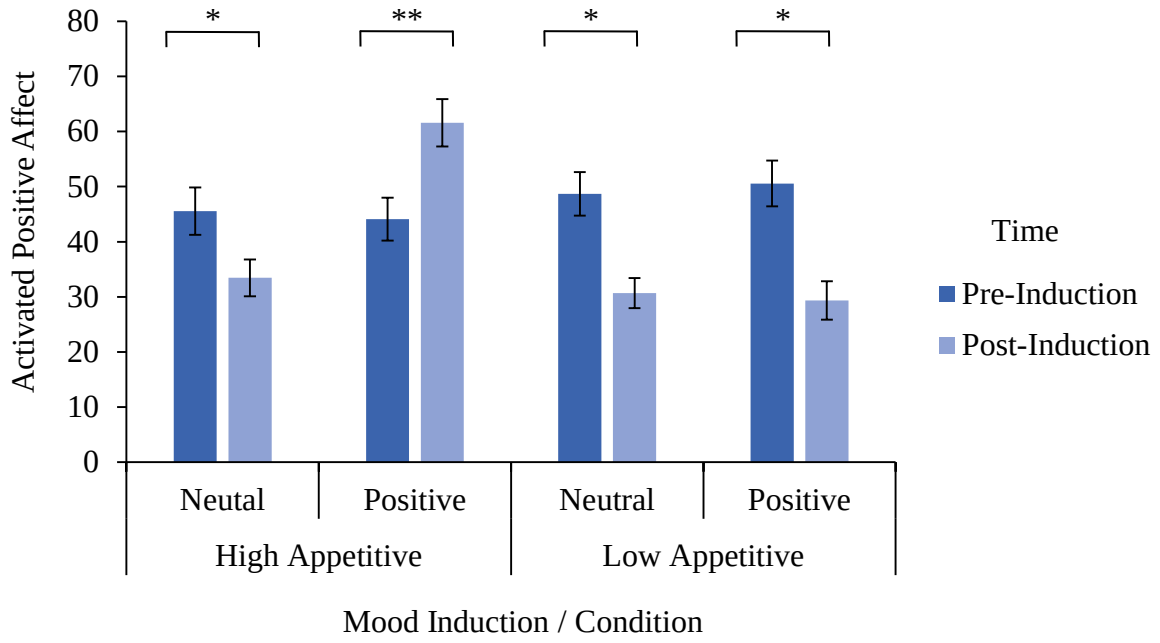


Figure 6.1. *Mood scores for activated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons * $p < .013$, ** $p < .003$.*

For the high appetitive condition, Figure 6.1 demonstrates that there was a significant increase in activated positive affect [$t(20) = 3.81$, $p < .001$, $d = 1.01$] for the positive induction ($M = 43.55$, $SD = 17.11$ to $M = 61.86$, $SD = 18.88$). For the low appetitive condition, Figure 6.1 demonstrates that there was a significant decrease in activated positive affect [$t(21) = -3.94$, $p = .001$, $d = -1.03$], which was also the case for neutral inductions in both mood conditions (t's ≥ -3.15, p's $\leq .003$, d's ≥ -0.68).

Therefore, this suggests that the mood induction was effective, in terms of producing an increase in activated positive affect in the positive induction only for the high appetitive condition.

Furthermore, independent t-tests also revealed that there was no significant difference in activated positive affect between the high and low appetitive mood conditions at the pre-induction time point for either the neutral [$t(42) = -0.69$, $p = 0.495$, $d = -0.21$], or positive

inductions (*t*'s ≤ -1.12, *p*'s ≥ .268, *d*'s ≤ -0.34). Therefore, this indicates that there were no differences in activated positive affect between mood conditions prior to the induction manipulation.

6.4.2.2. Deactivated Positive Affect

The ANOVA results for deactivated positive affect are displayed in Table 6.2, which demonstrates that there were no significant main effects or lower order interaction effects (*p*'s ≥ .149), other than a marginally significant time by mood condition interaction. However, the pertinent time by induction by mood condition interaction was also found to be significant.

Table 6.2. *ANOVA results for differences in deactivated positive affect depending on time, induction, and mood condition.*

Effect	df	*F*	*p*	η^2_p
Time	1, 41	2.16	.149	0.05
Induction	1, 41	1.59	.214	0.04
Mood Condition	1, 41	1.38	.247	0.03
Time by Induction	1, 41	0.00	.998	0.00
Time by Mood Condition	1, 41	4.20	.047	0.09
Time by Induction by Mood Condition	1, 41	16.40	< .001	0.30

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in deactivated positive affect within different mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons (α = .013). The mean scores for this analysis are displayed in Figure 6.2.

For the low appetitive condition, Figure 6.2 demonstrates that there was a significant increase in deactivated positive affect for the positive induction [$t(21) = 4.10$, $p < .001$, $d = 0.97$]. However, a decrease approached significance for the low appetitive condition [$t(20) = -2.04$, $p = .028$, $d = -0.48$], and there was no significant change in deactivated positive affect as a result of the neutral inductions for either of the mood conditions (*t*'s ≤ 1.29, *p*'s ≥ .105, *d*'s ≤ 0.14).

Therefore, this suggests that the mood induction was effective, in terms of resulting in an increase in deactivated positive affect for only the low appetitive condition.

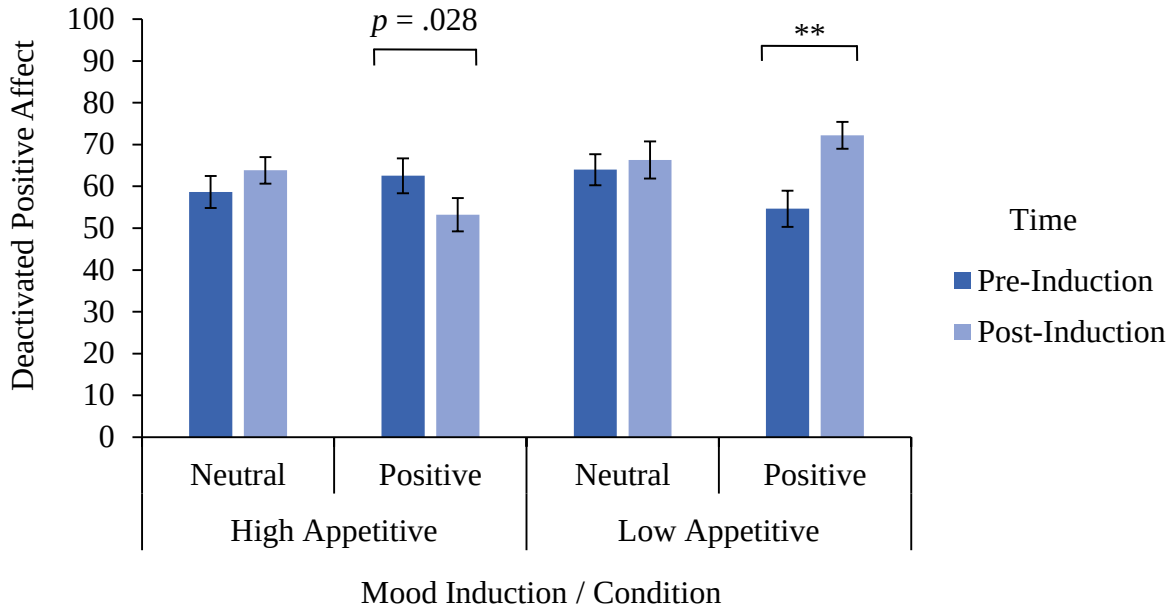


Figure 6.2. *Mood scores for deactivated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons * p < .013, ** p < .003.*

Furthermore, independent t-tests also revealed that there was no significant difference in deactivated positive affect between mood conditions at the pre-induction time point for either the neutral [$t(42) = -1.12$, $p = .268$, $d = -0.34$] or positive inductions (t's ≤ 1.24, p's $\geq .224$, d's ≤ 0.38). Therefore, this indicates that there were no differences in deactivated positive affect between mood conditions prior to the induction manipulation.

6.4.3. Effect of Mood on Set-Shifting

One participant was excluded from the set-shifting analysis due to a reported learning disability that may have impacted performance. Therefore, $N = 42$ for this analysis, with $n = 20$ for the high appetitive condition and $n = 22$ for the low appetitive condition.

The mean error rate was 4.05% (comparable to 4.15% in Dreisbach & Goschke, 2004) and error rates were all within three standard deviations of the mean. RTs above 2,000 ms were excluded from analysis.

There were three switch cost outliers: two high values (greater switch costs) for the distraction switch condition (neutral induction in the high appetitive mood condition) and one high value for the perseveration condition (positive induction in the low appetitive mood condition). These

were winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall patterns observed within this analysis.

Data was positively skewed for RTs, but this should not be problematic for ANOVA analysis, as simulation studies consistently demonstrate that this is robust against even moderate deviations from normality (e.g., Schmider et al., 2010). Furthermore, using a natural log transformation to correct for this (Harmon-Jones & Amodio, 2012; Whelan, 2008), did not change the results.

6.4.3.1. Switch Costs

A 2 (switch condition: perseveration/distraction) by 2 (compatibility: compatible/incompatible) by 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed design ANOVA was conducted, with switch costs entered as the dependent variable.

There were no significant main effects for switch condition [$F(1,40) = 2.36$, $p = .132$, $\eta^2p = 0.06$], induction [$F(1,40) = 1.56$, $p = .219$, $\eta^2p = 0.04$], or mood condition [$F(1,40) = 1.23$, $p = .274$, $\eta^2p = 0.03$]. However, the expected main effect for compatibility was significant [$F(1,40) = 69.87$, $p < .001$, $\eta^2p = 0.64$], and switch costs were greater for incompatible ($M = 122.99$, $SD = 88.30$) compared to compatible trials ($M = -6.72$, $SD = 57.58$).

As compatibility did not interact with any other factor (p's $\geq .220$), the following analysis is performed by collapsing switch costs across compatible and incompatible trials, producing overall switch costs for conditions (Dreisbach et al., 2005; Liu & Wang, 2014; Tharp & Pickering, 2011).

A second 2 (switch condition: perseveration/distraction) by 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed design ANOVA was conducted, with switch costs as the dependent variable.

The results of this ANOVA are displayed in Table 6.3, which demonstrates that there were no significant main or interaction effects (p's $\geq .134$). This includes the pertinent induction by switch by mood condition interaction.

Table 6.3. *ANOVA results for switch costs depending on switch condition, induction, and mood condition.*

Effect	df	*F*	*p*	η^2_p
Switch Condition	1, 40	1.28	.265	0.03
Induction	1, 40	2.34	.134	0.06
Mood Condition	1, 40	1.57	.218	0.04
Switch by Induction	1, 40	0.45	.505	0.01
Switch by Mood Condition	1, 40	1.61	.212	0.04
Induction by Mood Condition	1, 40	1.66	.205	0.04
Switch by Induction by Mood Condition	1, 40	1.15	.290	0.03

Despite the lack of a significant interaction effect, planned contrasts were conducted with paired t-tests to confirm that there were no differences in switch costs for mood conditions. A Bonferroni correction applied to correct for inflated Type I error due to the four multiple comparisons ($\alpha = .013$). The means for this analysis are displayed in Figure 6.3.

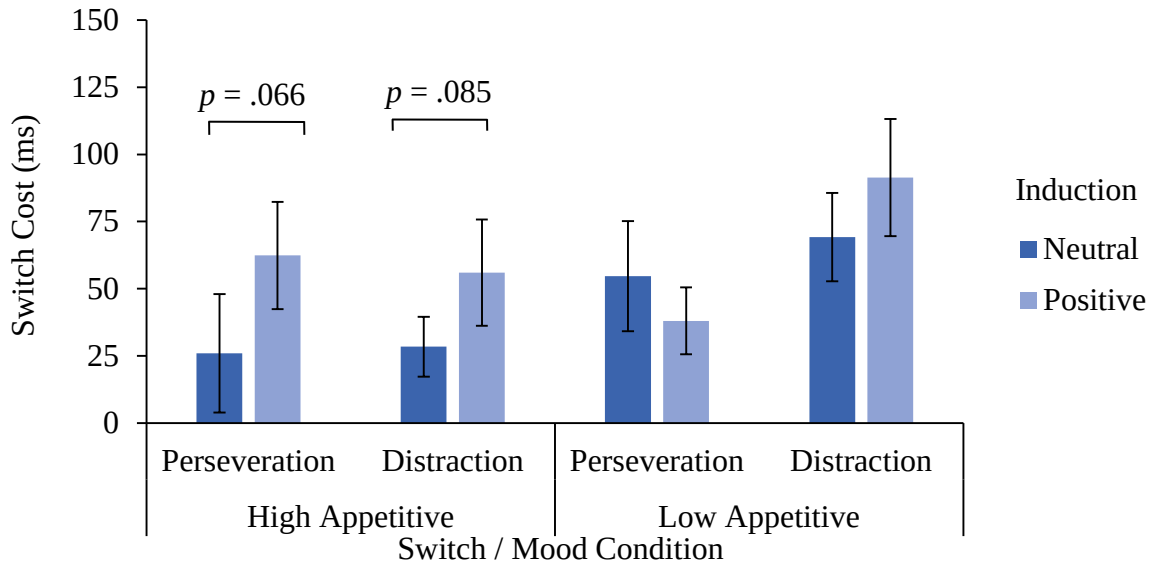


Figure 6.3. *Switch costs for set-shifting switch conditions for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons (α = .013).*

For the low appetitive mood condition, Figure 6.3 demonstrates that there was a decrease in switch costs for the perseveration condition, but this was not significant [$t(21) = -0.75$, $p = .231$

d = -0.21]. In contrast, there was an increase in switch costs for the distraction condition, but again this was not significant [*t*(21) = 0.91, *p* = .186, *d* = 0.24].

Although non-significant, the direction of results for switch conditions in the low appetitive condition are in line with predictions, with numerically decreased perseveration costs and numerically increased distraction costs, which indicates greater flexibility (cf., Dreisbach & Goschke, 2004; Liu & Wang, 2014).

For the high appetitive condition, Figure 6.3 demonstrates that there was a trend towards significance for increased switch costs in both the perseveration [*t*(19) = 1.57, *p* = .066, *d* = 0.37] and the distraction condition [*t*(19) = 1.43, *p* = .085, *d* = 0.36].

Whilst an increase in switch costs in the perseveration condition was in line with expectations (i.e., reduced flexibility) for the high appetitive condition, a similar effect in the distraction condition was not. The distraction condition was expected to result in the opposite pattern of findings, such that there would be a decrease in switch costs following the positive induction in this condition.

To examine whether there were any pre-induction differences between mood conditions, paired t-tests were also conducted to compare switch costs in the neutral induction for the high and low appetitive mood conditions. Levene's test for homogeneity of variance was significant for the distraction condition, therefore equal variances cannot be assumed for this comparison. However, this should not be problematic for analysis.

No significant differences were found between mood conditions for switch costs in the perseveration condition [*t*(41) = -0.97, *p* = .338, *d* = -0.28], but switch costs for the distraction condition were found to be significantly lower for high compared to low appetitive mood [*t*(36.54) = -2.11, *p* = .042, *d* = -0.64], [(*M* = 27.27, *SD* = 50.92) vs. (*M* = 69.23, *SD* = 77.20)].

Therefore, this suggests that there may have been some pre-existing differences affecting performance between the high and low appetitive conditions. Although this is worth noting, it should not be too problematic for analysis, as comparisons were made within mood conditions.

6.4.3.2. Distractor Compatibility Effects

To see whether mood inductions may exert effects on the inhibition of the distractors, variables were calculated to assess distractor compatibility effects. As was the case in Study 3, RTs for

pre-switch trials were collapsed across switch conditions, and RTs for compatible trials were subtracted from incompatible trials.

There was one outlier - a low value (positive induction in the high appetitive mood condition) that was winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall patterns observed within analysis.

A 2 (induction: neutral/positive) by 2 (high appetitive/low appetitive) mixed ANOVA was conducted with the distractor compatibility effect variable entered as the dependent variable. However, there were no significant main effects (F's ≤ 2.89, p's $\geq .097$, $\eta^2p \leq 0.07$) and the pertinent induction by mood condition interaction was also not significant [$F(1,40) = 1.04$, $p = .313$, $\eta^2p = 0.03$].

To confirm that there were no differences in distractor compatibility effects between the mood conditions, planned contrasts with paired t-tests were conducted. A Bonferroni correction for inflated Type I error due to the three multiple comparisons ($\alpha = .016$) was applied. The means for this analysis are displayed in Figure 6.4.

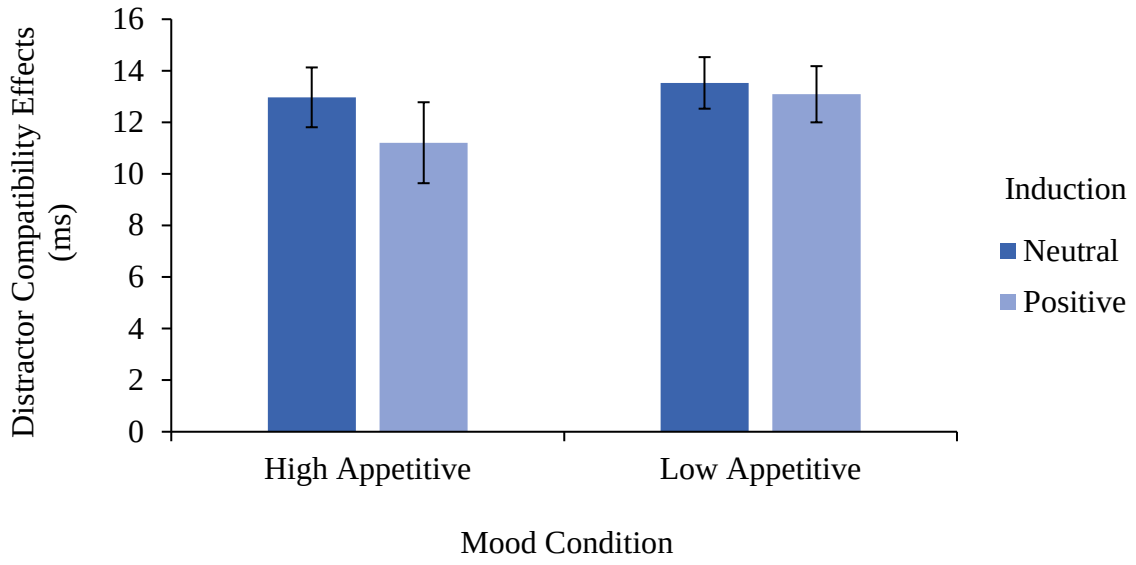


Figure 6.4. *Distractor compatibility effects for each mood condition. Error bars reflect one standard error above and below the mean.*

For the low appetitive condition, Figure 6.4 demonstrates that there was no significant difference in distractor compatibility effects [$t(21) = 0.84$, $p = .411$, $d = 0.09$]. However, for the high appetitive condition, Figure 6.4 demonstrates that there was a numerical decrease in

distractor compatibility effects in for the positive induction, although this was not significant [$t(19) = 1.43$, $p = .169$, $d = 0.26$].

It is interesting to note that this pattern arises – that the high appetitive positive induction may have enhanced distractor inhibition (i.e., there was less interference from distractor stimuli across trials). However, this pattern was far from significance and thus must be interpreted with caution.

Furthermore, an independent t-test demonstrated that there was no difference in distractor compatibility effects between the positive mood conditions [$t(41) = -0.30$, $p = .766$, $d = -0.09$].

The relationships between positive affect and the distractor compatibility effect variable were also explored. Interestingly, there was a moderate negative correlation for change in activated positive affect [$r(42) = -.33$, $p = .018$], whilst a correlation for change in deactivated positive affect was far from significant [$r(42) = -.05$, $p = .732$].

This suggests that increases in activated positive affect, but not deactivated positive, were related to enhanced distractor inhibition following the positive mood inductions.

6.4.4. Effect of Mood on EBR

One participant was removed from EBR analyses due to reporting a medical condition that may have affected visual sensitivity (Barbato et al., 2000). Therefore, $N = 42$ in this analysis, with $n = 20$ in the high appetitive condition and $n = 22$ in the low appetitive condition.

There was one value following the positive mood induction in the low appetitive condition that met criteria as an outlier. This was winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall pattern or significance of results for these analyses.

To examine the effect of mood inductions on EBR, a 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVA was conducted with EBR as the dependent variable. Although Levene's test for homogeneity of variance was significant for EBR during the positive induction, this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups when cell sizes are approximately equal (Zimmerman, 2004).

This analysis found that there were no significant main effects of induction or mood condition (F's ≤ 2.53, p's $\geq .119$, $\eta^2p \leq 0.06$). However, the pertinent induction by mood condition interaction was found to be significant [$F(1,40) = 4.33$, $p = .044$, $\eta^2p = 0.10$].

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in EBR within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to the two multiple comparisons (α = .025). Mean scores are displayed in Figure 6.5.

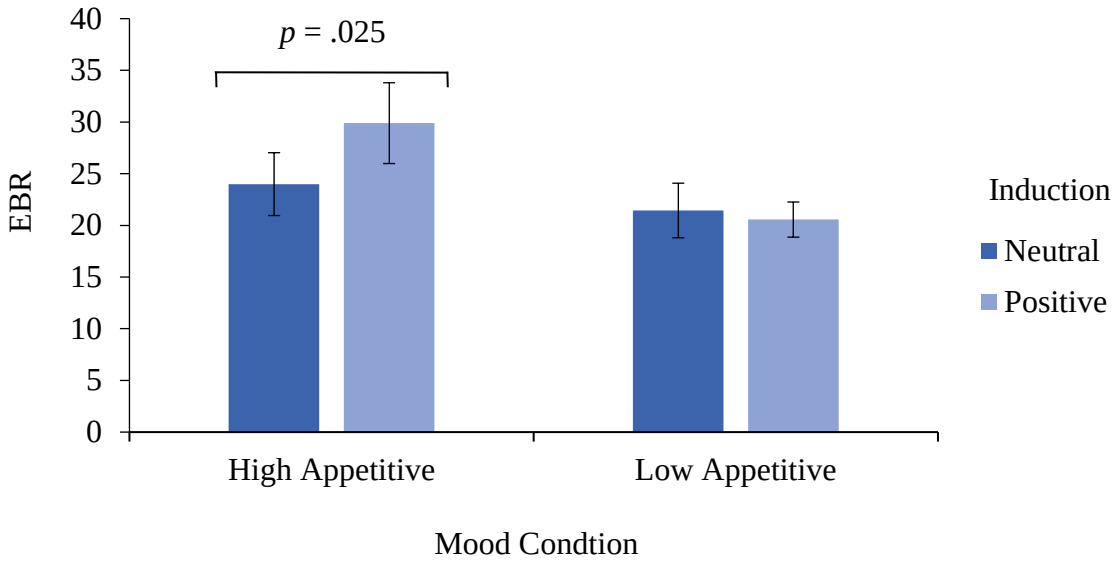


Figure 6.5. *EBR for different inductions within mood conditions. Error bars reflect one standard error above and below the mean. Bonferroni correction for two multiple comparisons (α = .025).*

For the high appetitive condition, Figure 6.5 demonstrates that there was a significant increase in EBR following the positive induction [$t(19) = 2.09$, $p = .025$, $d = 0.38$], [($M = 29.89$, $SD = 17.47$) vs. ($M = 23.99$, $SD = 13.59$)]. However, for the low appetitive condition Figure 6.5 demonstrates that there was no significant difference in EBR [$t(19) = -0.47$, $p = .321$, $d = -0.08$].

Therefore, this suggests that appetitive motivation moderated the influence of positive mood on EBR, such that an increase in EBR occurred only for positive mood that was high in appetitive motivation.

6.4.5. Relationship between Neutral EBR and Set-Shifting

Chermahini and Hommel (2012) demonstrated that baseline EBR may be related to flexibility on other more complex cognitive tasks assessing cognitive flexibility (i.e., divergent thinking) in an inverted U-shape. Therefore, the possibility of linear and quadratic relationships between EBR and set-shifting switch costs were examined in the neutral induction.

Separate regression analyses were conducted with switch costs for the perseveration and distraction conditions. To avoid potentially problematic high multicollinearity with the quadratic term, these variables were centred (Aiken & West, 1991). For all analyses, EBR was entered in the first step to test a linear fit, and the quadratic term (centred EBR value squared) was entered in the second step. Regression lines for these models are displayed in Figure 6.6 for the perseveration condition and Figure 6.7 for the distraction condition.

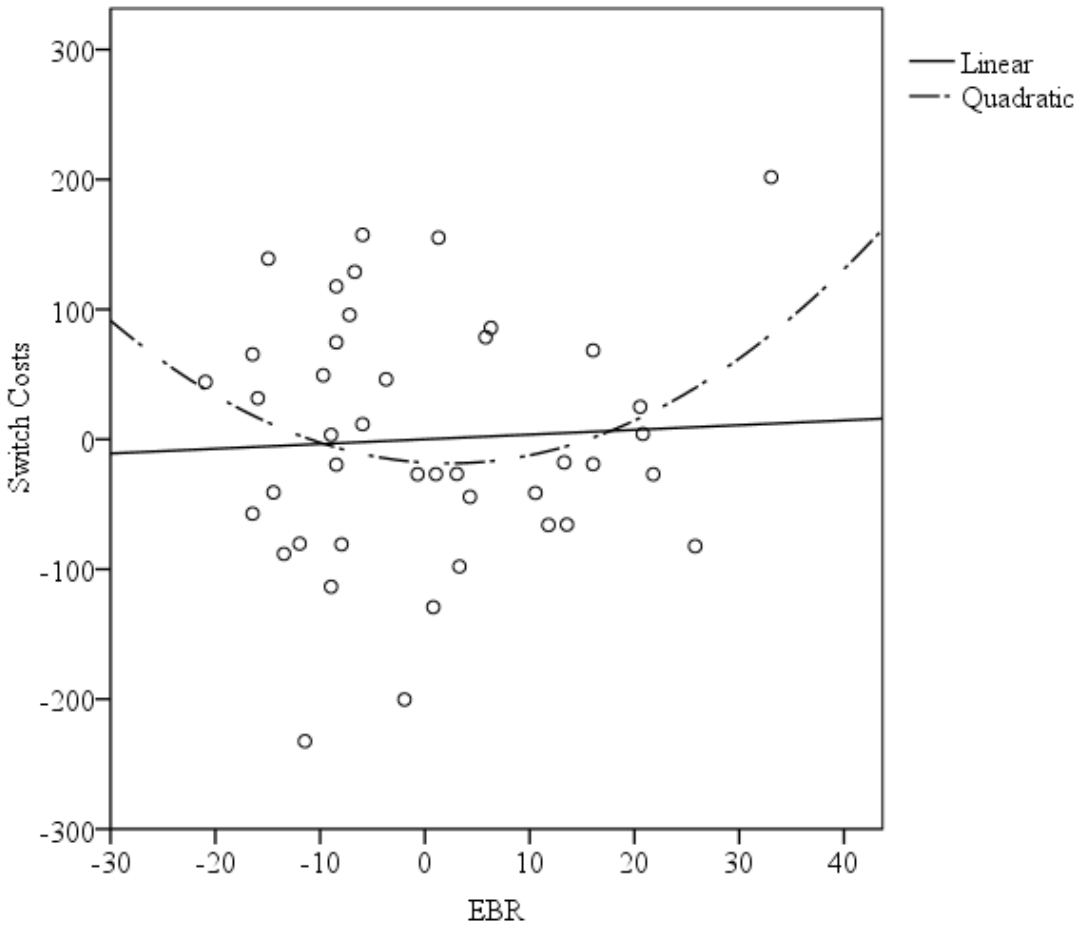


Figure 6.6. *Perseveration switch costs as a function of EBR for the neutral induction.*

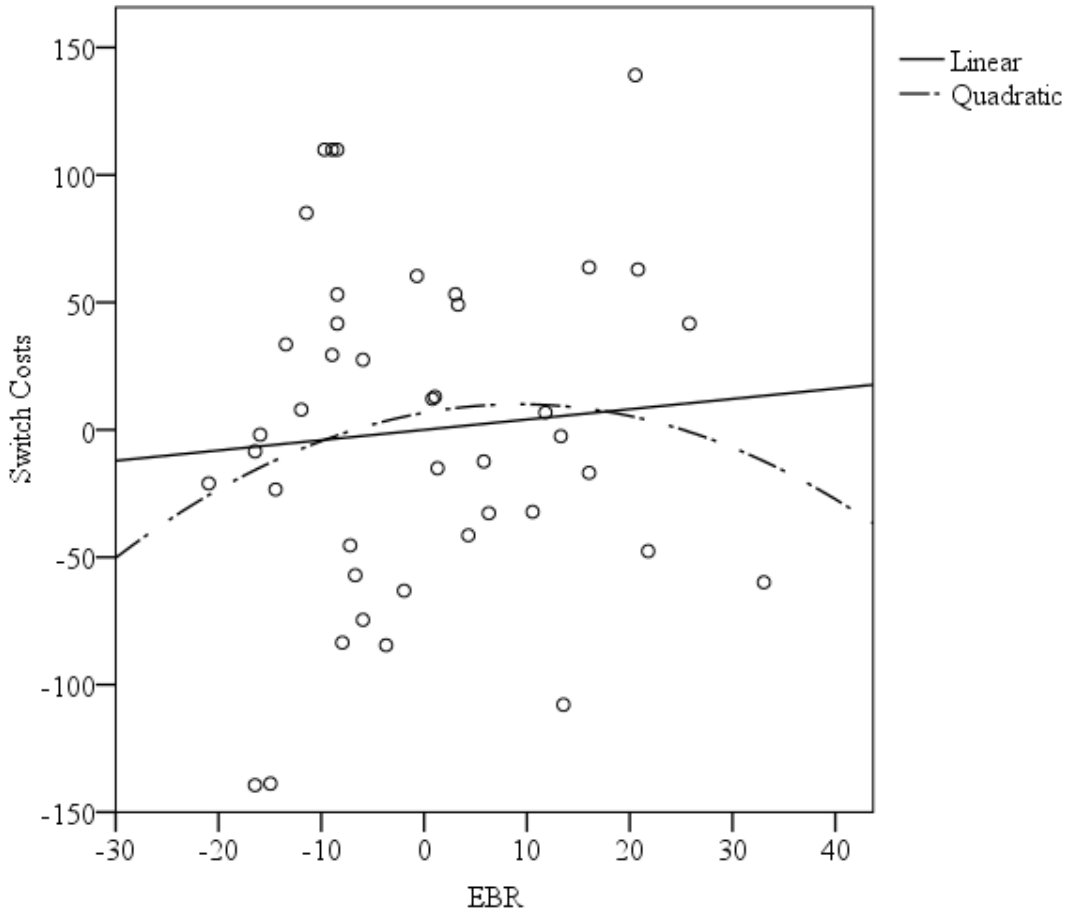


Figure 6.7. *Distraction switch costs as a function of EBR for the neutral induction.*

These figures both show that there were no linear or quadratic relationship between EBR and set-shifting for the neutral induction.

This was supported by findings that for the perseveration condition, the linear model was far from significance [$R2$= .00, $F(1,40) = 0.10$, $p = .749$], and adding the quadratic term did not explain additional variance [$\Delta R2 = .00$, $F(2,39) = 0.08$, $p = .925$].

This was also the case for the distraction condition, as the linear model was also non-significant, [$R2$= .01, $F(1,40) = 0.26$, $p = .611$], and adding the quadratic term did not explain additional variance [$\Delta R2 = .01$, $F(2,39) = 0.39$, $p = .677$].

6.4.6. Effect of Neutral EBR on Set-Shifting

To confirm the lack of quadratic relationship between EBR and switch costs, a median split was conducted on EBR for the neutral induction, so that participants were ranked as above or below the median (Mdn = 19.75, IQR = 20.25). This is in line with analysis from previous

studies examining this effect (Dreisbach et al., 2005; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011). For the high EBR group n = 21 and for the low EBR group n = 21.

A 2 (EBR: low/high) by 2 (switch condition: perseveration/distraction) mixed design ANOVA was conducted, with switch costs as the dependent variable.

The results of this analysis demonstrated that there were no significant main effects of EBR or switch condition (F's ≤ 0.28, p's $\geq .599$, $\eta^2p \leq 0.01$), and the pertinent EBR by switch condition interaction was also not significant [$F(1,40) = 0.63$, $p = .433$, $\eta^2p = 0.02$].

Despite the lack of a significant interaction, planned contrasts were conducted using simple effects analysis with independent t-tests to confirm that there were no differences in switch costs for those with higher and lower EBR in the neutral induction. A Bonferroni correction was used ($\alpha = .025$), due to two multiple comparisons, and the means for this analysis can be seen Figure 6.8.

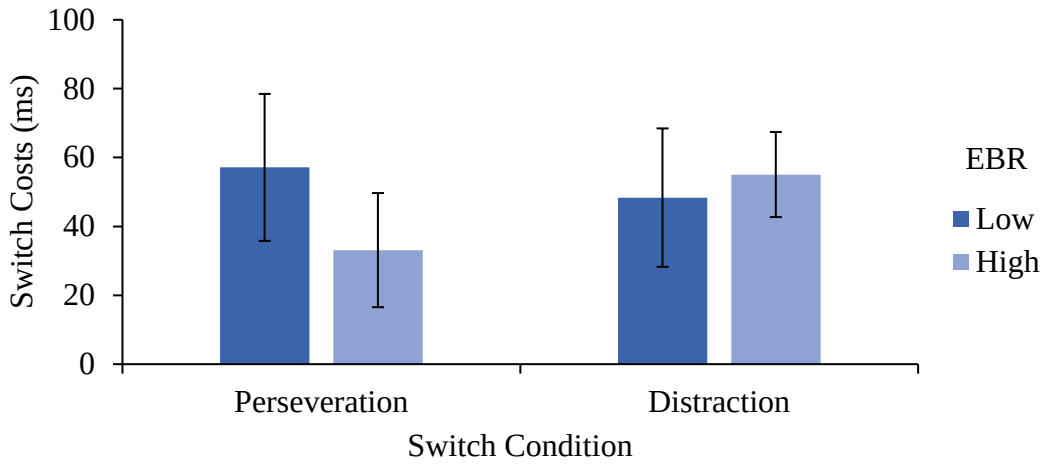


Figure 6.8. *Switch costs for different switch conditions for individuals with a higher or lower EBR in the neutral induction. Error bars reflect one standard error above and below the mean. Bonferroni correction for two multiple comparisons.*

For individuals with a higher EBR, Figure 6.8 demonstrates that there was a general trend towards lower switch costs in the perseveration condition, and greater switch costs in the distraction condition, compared to those with a lower EBR. However, neither of these effects were significant [perseveration: $t(40) = 0.82$, $p = .209$, $d = 0.25$, distraction: $t(40) = -0.32$, $p = .374$, $d = -0.10$].

Therefore, this is only somewhat in line with previous findings from studies demonstrating reduced switch costs in the perseveration condition and greater switch costs on the distraction condition of this paradigm for those with a higher EBR (Dreisbach et al., 2005).

6.4.7. Moderating Effect of Neutral EBR on Positive Mood and Set-Shifting

To examine whether EBR moderated the effect of positive mood on set-shifting performance, two separate 2 (EBR: low/high) by 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed design ANOVAs were conducted, with switch costs in the perseveration and distraction conditions as dependent variables. Levene's test of homogeneity of variance was significant for perseveration switch costs for the positive induction and distraction switch costs for the neutral induction, which should not be problematic for analysis due to approximately equal sample sizes.

6.4.7.1. Perseveration Switch Costs

The results of this ANOVA for switch costs in the perseveration condition demonstrated that there were no significant main effects or lower-order interaction effects [$F(1,37) = 1.16$, $p = .288$, $\eta^2p = 0.03$], other than a significant induction by EBR interaction [$F(1,37) = 4.89$, $p = .033$, $\eta^2p = 0.12$]. However, the pertinent induction by mood condition by EBR interaction was not found to be significant [$F(1,40) = 5.34$, $p = .026$, $\eta^2p = 0.18$].

To further investigate the unexpected induction by EBR interaction, simple effects analysis using paired t-tests was conducted. This confirmed that there were no differences in switch costs for neutral and positive inductions for those with a lower EBR [$t(20) = 1.35$, $p = .193$, $d = 0.38$]. However, for those with a higher EBR, there was an increase in switch costs for the positive induction that approached (uncorrected) significance [$t(19) = -2.00$, $p = .060$, $d = -0.43$], [($M = 33.86$, $SD = 94.43$) vs. ($M = 73.71$, $SD = 90.20$)].

To confirm the lack of pertinent mood condition by induction by EBR interaction, planned contrasts were conducted with simple effects analysis using paired t-tests. Specifically, perseveration switch costs were compared between neutral and positive inductions separately dependent on mood condition and EBR. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons ($\alpha = .013$), and the mean scores for this analysis are displayed in Figure 6.9.

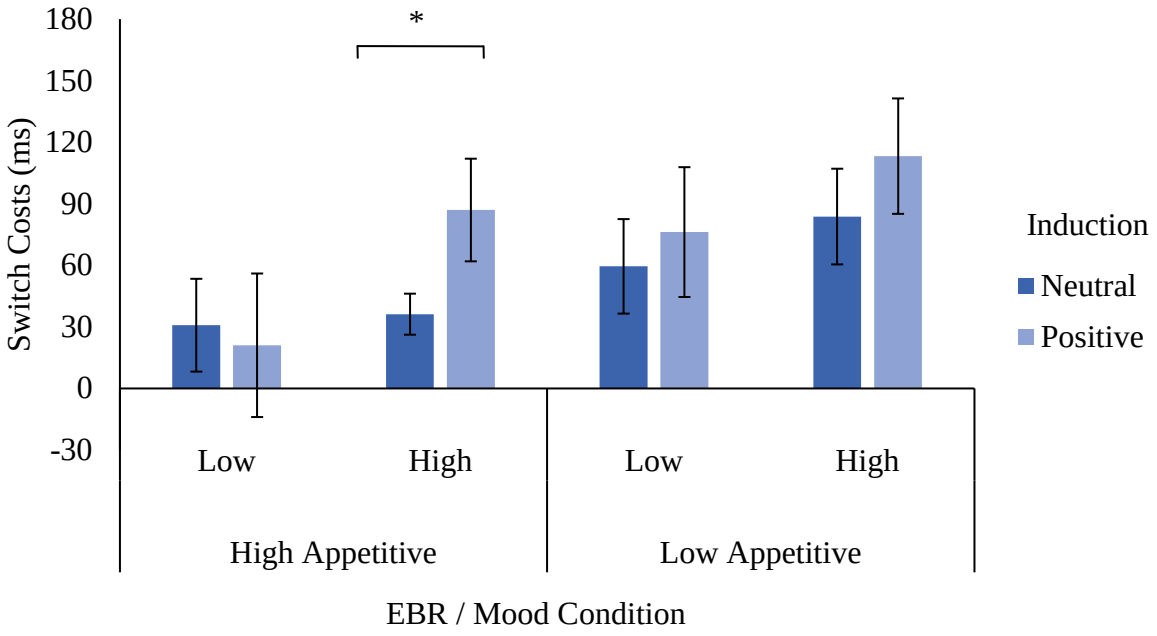


Figure 6.9. *Perseveration switch costs as a function of induction, mood condition, and EBR (neutral induction) Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons (α = .013).*

Figure 6.9 confirms that there were largely no significant differences in switch costs between neutral and positive inductions (*t*'s ≤ 1.13, *p*'s ≥ .148), other than for a significant increase in switch costs in the high appetitive condition for those with a higher EBR [*t*(10) = -3.00, *p* = .007, *d* = -0.65], [(*M* = 23.15, *SD* = 110.24 vs. *M* = 95.54, *SD* = 110.85)].

Although common practice in research examining EBR, dictomising this variable by performing a median split may be problematic because it results in a loss of statistical power, which can increase the chance of Type II error (Aiken & West, 1991). Therefore, regression analysis was also conducted to examine whether neutral EBR moderated the effect of the positive mood inductions on switch costs in the perseveration condition.

Switch costs for the positive induction were entered as the dependent variable. In the first step, neutral switch costs and neutral EBR were entered as continuous predictor variables. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect the low (=0) and high appetitive (=1) conditions. In the second step, a product term was also entered, to reflect the interaction between neutral EBR and mood condition. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

There was a significant overall model effect at step one [R^2= .33, F(3,37) = 6.10, p = .002]. Individual predictors for this model are displayed in Table 6.4, which demonstrates that neutral switch costs and neutral EBR both significantly predicted switch costs following the positive induction. Examination of the coefficients suggests that switch costs for the positive induction were predicted by greater neutral switch costs and a greater EBR.

Table 6.4. *Coefficients and significance values for individual predictors in regression models for moderation of perseveration switch costs following the positive induction by mood condition and neutral EBR*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Switch Costs	.25	.11	.30	1.23	.032
Mood Condition	20.97	21.07	.14	1.00	.326
EBR	2.68	.82	.44	3.27	.002
Step 2					
Switch Costs	.23	.11	.28	2.08	.045
Mood Condition	21.59	20.83	.14	1.04	.307
EBR	1.55	1.16	.26	1.34	.188
Mood Condition by EBR	2.23	1.63	.26	1.37	.179

Although additional variance was not explained by adding the interaction term for neutral EBR and mood condition [ΔR^2= .03, F(1,36) = 1.88 p = .179], coefficients are in line with ANOVA analysis, as greater switch costs following the high appetitive condition were (non-significantly) predicted by a greater neutral EBR.

Therefore, this suggests that, for the high appetitive condition, only those with a higher baseline EBR had an increase in perseveration switch costs following the positive induction.

6.4.7.2. Distraction Switch Costs

The results of this ANOVA for switch costs in the distraction condition demonstrated that a main effect of induction approached significance [F(1,37) = 3.60, p = .066, η^2p = 0.09], such that switch costs were greater in the low (M = 83.09, SD = 66.37) compared to high appetitive condition (M = 43.76, SD = 66.22). However, all other main effects and interaction effects were found not to be significant [F(1,37) ≤ 2.57, p ≥ .118, η^2p ≤ 0.07], including the pertinent induction by mood condition by EBR interaction [F(1,37) = 0.54, p = .467, η^2p = 0.01].

To confirm the lack of mood condition by induction by EBR interaction, planned contrasts were conducted with simple effects analysis using paired t-tests. Specifically, distraction switch costs were compared between neutral and positive inductions separately dependent on mood condition and EBR. A Bonferroni correction was used to correct for inflated Type I error due to the two multiple comparisons ($\alpha = .013$), and the mean scores for this analysis are displayed in Figure 6.10.

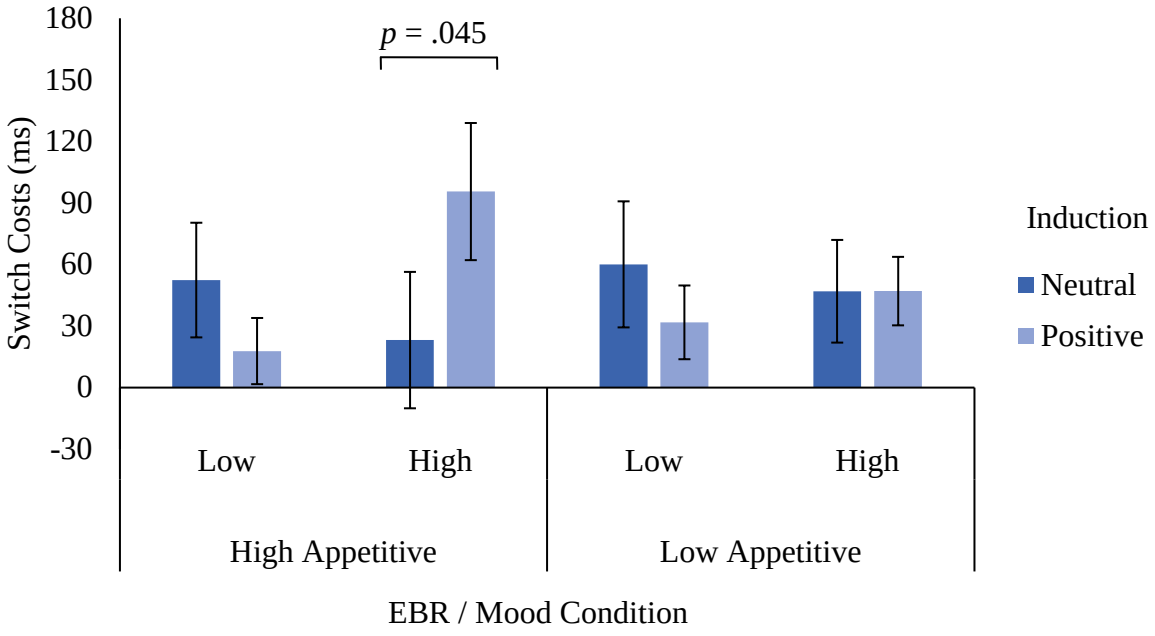


Figure 6.10. *Distraction switch costs as a function of induction, mood condition, and EBR (in neutral induction) Error bars reflect one standard error above and below the mean. Bonferroni correction for four multiple comparisons (α = .013).*

Figure 6.10 confirms that there were largely no significant differences in switch costs between neutral and positive inductions (t's ≤ 0.90, p's ≥ .198), other than for a trend towards a significant increase in for the positive induction in the high appetitive condition for those with a higher EBR [$t(10) = -1.87$, $p = .045$, $d = -0.80$], [($M = 36.20$, $SD = 33.16$ vs. $M = 86.97$, $SD = 82.95$)].

Therefore, this suggests that there was some evidence that, for the high appetitive condition, only those with a higher baseline EBR had an increase in distraction switch costs following the positive induction.

Again, regression analysis was also conducted to examine whether neutral EBR moderated the effect of the positive mood inductions on switch costs in the distraction condition.

Switch costs for the positive induction were entered as the dependent variable. In the first step, neutral switch costs and neutral EBR were entered as continuous predictor variables. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect the low (=0) and high appetitive (=1) conditions. In the second step, a product term was also entered, to reflect the interaction between neutral EBR and mood condition. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

There was a significant overall model effect at step one [R^2= .47, F(3,37) = 3.81, p = .018]. Individual predictors for this model are displayed in Table 6.5, which demonstrates that only neutral EBR significantly predicted switch costs following the positive induction, such that greater switch costs were predicted by a greater neutral EBR.

Table 6.5. *Coefficients and significance values for individual predictors in regression models for moderation of distraction switch costs following the positive induction by mood condition and neutral EBR*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Switch Costs	.31	.22	.21	1.38	.176
Mood Condition	-30.58	29.50	-.16	-1.04	.307
EBR	2.92	1.12	.38	2.62	.013
Step 2					
Switch Costs	.32	.23	.21	1.39	.174
Mood Condition	-30.01	29.93	-.15	-1.00	.323
EBR	2.56	1.62	.34	1.58	.123
Mood Condition by EBR	.67	2.25	.07	.311	.758

No additional variance was explained by adding the interaction term for neutral EBR and mood condition [ΔR^2= .00, F(1,36) = .10 p = .758].

Therefore, results are mostly in line with the ANOVA analysis, in terms of demonstrating that neutral EBR does not moderate the effect of positive mood inductions on distraction switch costs.

6.5. Discussion

6.5.1.1. Motivational Intensity Model

The primary aim of the present study was to examine the effect of positive mood states that were high and low in appetitive motivation on Dreisbach and Goschke's (2004) attentional set-shifting paradigm. It was expected that appetitive motivation would moderate the influence of positive mood on switch costs (cf. Liu & Wang, 2014). However, appetitive motivation was not found to have an overall moderating effect for the influence of the positive mood inductions across switch costs. Despite this, some interesting patterns did emerge when the perseveration and distraction switch costs were examined separately within the mood conditions. For the low appetitive condition, it was hypothesised that there would be greater flexibility in cognitive control (at the cost of increased distractibility), demonstrated by decreased switch costs in the perseveration condition and increased switch costs in the distraction condition. Although non-significant, there was a trend towards this general pattern of results in the present study, which provides some evidence of greater flexibility in cognitive control for positive affect that was low in appetitive motivation.

This replicates the effects of positive affect that were originally observed by Dreisbach and Goschke (2004) on this paradigm. Although the motivational intensity of affect induced in this original study was not clearly specified, Liu and Wang (2014) later demonstrated that this pattern of results was specific only to positive affect that was low in appetitive motivation. The trend towards greater flexibility in cognitive control (at the cost of increased distractibility) only for the low appetitive positive mood induction in the present study is in line with these previous findings. These results also provide support for the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that only positive affect low in appetitive motivation results in broader cognition. This suggests that the original model, based on findings related to attentional scope, can be extended to the balance between flexibility and stability in cognitive control.

The positive mood induction that was low in appetitive motivation was found to follow the same pattern as previous studies (i.e., Liu & Wang, 2014), which induced positive affect using the brief presentation of affective images prior to each trial. These studies likely induced transient emotional responses compared to the more enduring mood states in the current study, which may explain the weaker effects that were observed. This is based on the suggestion that emotional responses are generally of a moderate to strong intensity, and directly linked to goals and action readiness, whilst mood states are of a lower intensity and are more "diffuse" –

typically less directly related to specific goals and action readiness (Frijda, 1993). Therefore, more enduring positive mood states may have a weaker effect on the balance between flexibility and stability in cognitive control processes, but one that is in line with transient emotional responses. Additionally, EEG recording may have contributed to weakened effects, as this may have been distracting for participants.

The motivational intensity model also suggests that positive affect high in appetitive motivation has the opposite (i.e., narrowing) effect on cognition (Gable & Harmon-Jones, 2010). This is predominantly based on studies examining attentional scope (e.g., Gable & Harmon-Jones, 2008b), but Liu and Wang (2014) also demonstrated that positive affect high in appetitive motivation results in attenuated flexibility (i.e., greater stability) on the set-shifting paradigm. Therefore, it was hypothesised for the present study that positive mood inductions high in appetitive motivation would replicate these results (i.e., switch costs increased for perseveration condition, but decreased for distraction condition). However, a trend was observed towards increased switch costs across both switch conditions, suggesting that positive affect high in appetitive motivation had a general and detrimental effect on performance. While this does not suggest reduced flexibility for positive mood high in appetitive motivation, it does provide some evidence of partially divergent effects compared to positive mood that is low in appetitive motivation as will be discussed further below.

6.5.1.2. Reward-as-Motivation Hypothesis

The finding that positive mood high in appetitive motivation had a non-specific and detrimental effect across both switch conditions also goes against predictions from the reward-as-motivation hypothesis (Goschke & Bolte, 2014). This hypothesis suggests that appetitive motivation results in greater stability (i.e., reduced flexibility) in cognitive control, but only when pursuing an incentive (i.e., active appetitive goal) that is dependent on task performance. This is supported by findings that presenting cues to indicate the availability of performance-based monetary incentives results in reduced flexibility on Dreisbach and Goschke's (2004) set-shifting paradigm (Muller, Dreisbach, Goschke, et al., 2007). Furthermore, this account proposes that positive affect that is unrelated to task performance results in greater flexibility, as this promotes engagement in new goals and opportunities (Carver, 2003). Therefore, the finding that the high and low appetitive inductions had partially divergent effects on performance in the present study is not in line the reward-as-motivation hypothesis, as both of these positive mood inductions were unrelated to task performance.

However, it is unclear why Liu and Wang (2014) found that positive affect high in appetitive motivation resulted in reduced flexibility on the set-shifting paradigm, whereas the present study did not. This may be due to the use of briefly presented appetitive images prior each trial, which is likely to induce transient emotional responses. This manipulation of affect is also very similar to the presentation of cues used to indicate the availability of performance-based monetary incentives in Muller, Dreisbach, Goschke, et al.'s (2007) study, and both found that stability was greater and/or flexibility reduced using these affective pre-trial images. Therefore, it could be the case that the close temporal proximity between the presentation of the appetitive stimuli and task responses is producing the observed effects in these studies. In contrast, inducing a more enduring positive mood state high in appetitive motivation, as was the case within the present study, may not have resulted in the same effects, as affect was not embedded within the task (i.e., did not occur in close temporal proximity to stimulus processing and response).

The reward-as-motivation hypothesis proposes that incentives facilitate greater stability in cognitive control because these serve to enhance motivation to engage in effortful control (Aston-Jones & Cohen, 2005). It is suggested that task preparation is facilitated by enhanced maintenance of contextual information, thus it is imperative that incentives and contextual information are presented in close temporal proximity (Chiew & Braver, 2016). Therefore, the brief presentation of appetitive stimuli occurring prior to each trial on the set-shifting paradigm may reduce flexibility (i.e., facilitating stability) in cognitive control, specifically in relation to the demands of this task. This would result in increased perseveration and reduced distractibility as observed in previous studies inducing transient emotional responses high in appetitive motivation (i.e., Liu & Wang, 2014; Muller, Dreisbach, Goschke, et al., 2007). In contrast, positive mood states that are induced prior to the task may not result in attenuated flexibility, as this occurs at a temporal distance too great to allow enhanced maintenance of contextual information that is related specifically to the set-shifting task.

However, rather than having no effect on performance in the set-shifting task, if anything, positive mood high in appetitive motivation appeared to be detrimental to performance in both switch conditions. It could be speculated that this positive mood induction may still result in the adoption of greater effortful control (cf. Aston-Jones & Cohen, 2005), but rather than enhanced maintenance of contextual information relevant to performance on the set-shifting task (potentially increasing stability/decreasing flexibility), this may instead facilitate maintenance of (task-irrelevant) contextual information associated with the goal content of the

appetitive mood induction. This broad adoption of effortful control may lead to an increased working memory load (including information irrelevant to task performance) which might then be detrimental to the ability to exert efficient cognitive control during the attentional switches. This is supported by previous findings demonstrating that (lower) working memory capacity had a non-specific but detrimental effect on performance in both switch conditions on this set-shifting paradigm (Tharp & Pickering, 2011).

Interestingly, while there was no evidence of a divergent effect across the switch conditions, there was some indication in pre-switch performance that, unlike the low appetitive positive induction, the high appetitive induction was associated with increased stability. This was illustrated by the finding that, across all participants, greater increases in activated positive affect were associated with reduced distractor compatibility effects (possibly indicating enhanced inhibition of distractors), and there was a similar, albeit non-significant, reduction in distractor compatibility effects for the high appetitive positive mood induction. Tentatively, it might be suggested that the influence of the high appetitive induction on stability was demonstrated during pre-switch trials only, as the demands upon cognitive control are lower than in the attentional switch phase. In contrast, a general increase in effortful control and increased working memory load, as the result of the high appetitive positive induction, may have led to a more generalised pattern of impaired cognitive control on the more cognitively demanding switch phase (i.e., increased switch costs across both switch conditions).

6.5.2. Neurobiological Mechanisms

6.5.2.1. Positive Mood and EBR

The present study also aimed to examine, albeit indirectly, the neurobiological mechanisms underlying the effects of positive mood on cognitive control. EBR has previously been found to increase following a positive mood induction, which was assumed to be low in appetitive motivation (Chermahini & Hommel, 2012). However, pharmacological manipulations targeting D1 and D2 activity (associated primarily with increases in dopamine in the prefrontal cortex and basal ganglia), have both been found to increase EBR (Elsworth et al., 1991). Furthermore, Study 2 found that EBR was decreased during the low appetitive positive mood induction, and increased during the high appetitive induction. As positive affect high in appetitive motivation is associated with greater activity in the mesocorticolimbic pathway, it was suggested EBR may reflect dopamine levels in the prefrontal cortex. Therefore, an

exploratory approach was taken to examine this aim in the present study. However, in line with Study 2, EBR was found to be increased only in the high appetitive condition – although, unlike Study 2, no reciprocal decrease was observed for the low appetitive condition in the present study.

An increase in EBR in the high appetitive condition might reflect an increase in dopamine levels in the prefrontal cortex. It is suggested that an increase in dopamine in the prefrontal cortex results in greater tonic activity of D1 neurons, facilitating the stabilisation of working memory representations (Durstewitz & Seamans, 2008). This activity is proposed to facilitate the enhanced maintenance of contextual information as a result of reward incentives, resulting in reduced flexibility (and greater stability) on cognitive control paradigms (Braver, Gray, & Burgess, 2007). Above, it was suggested that more enduring mood states high in appetitive motivation may have a detrimental effect on Dreisbach and Goschke's (2004) set-shifting paradigm as contextual information relevant to goals activated by the content of the mood inductions is maintained. This is proposed to increase working memory load, resulting in reduced cognitive control when demands are high during the switching period of the task. Therefore, greater EBR in the high appetitive condition may still represent greater stabilisation of working memory representations, but the maintenance of contextual information that is not relevant to performance on the task.

As speculated above, the high appetitive mood induction may increase effortful control that engages greater working memory capacity (i.e., increases load). When task demands upon cognitive control are low, such as during pre-switch trials, increased effortful control may elicit increased stability (e.g., reduced distractor compatibility effects). Interestingly, additional analysis revealed that there was a moderate negative correlation between EBR and distractor compatibility effects during both the neutral and positive inductions (r's $\geq$ -.40, p's $\leq$ .009), which implies that those with a higher EBR were more able to inhibit distractors during pre-switch trials. This is in line with the idea that an increase in EBR reflects greater D1 activity in the prefrontal cortex, as this would imply greater stabilisation of task-relevant working memory representations. However, as discussed above, when cognitive demands are high, such as during the attentional switch, the greater load upon working memory/cognitive control, that may have contributed to the general slowing across both switch conditions for the high appetitive group, might mask such specific effects.

6.5.2.2. EBR and Set-Shifting

The present study also explored whether switch costs for the neutral induction were moderated by EBR, as those with a higher EBR have previously been demonstrated to have greater flexibility in cognitive control (i.e., switch costs were decreased in the perseveration, but increased in the distraction condition). This moderating effect is suggested to reflect greater dopamine activity in the basal ganglia for those with a higher EBR, and has been replicated in several studies (Dreisbach et al., 2005; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011). However, a moderating effect of EBR on set-shifting was not demonstrated in the present study, which could be due to some methodological differences. Specifically, EBR was assessed during the neutral mood induction in the present study, which meant that participants listened to music and imagined scenarios to induce neutral affect. Previous studies have examined EBR at baseline (i.e., in the absence of any mood induction procedure), so it is possible that the design of the present study had an effect EBR, which possibly reduced the comparative validity of this measurement.

Chermahini and Hommel (2012) found that, at baseline (i.e., in the absence of a mood induction), EBR was related to flexibility on a divergent thinking task, and this was such that it followed in an inverted U-shape. Based on these findings, the present study also examined the relationship between EBR and set-shifting costs for the neutral induction. However, an exploratory approach was taken due to a failure to replicate this relationship in previous studies (i.e., Studies 1 and 2). There was no evidence of any relationships (either linear or quadratic) between EBR and switch costs in either of the switch conditions. This is not in line with the inverted U-shaped relationship demonstrated by Chermahini and Hommel (2010), or the negative linear relationships demonstrated in Studies 1 and 2. It may be expected that EBR would be associated with switch costs, if this is assumed to reflect enhanced active maintenance and increased effortful control. However, it may be the case that this relationship only emerges after the positive mood induction that is high in appetitive motivation.

6.5.2.3. Positive Mood, EBR, and Set-Shifting

Chermahini and Hommel (2012) also found that a positive mood induction resulted in greater flexibility in divergent thinking, but only for those with a lower EBR, which is in line with an inverted U-shaped relationship between these variables at baseline. The present study explored the moderating effect of EBR at baseline (in the neutral condition) in relation to the influence

of positive mood on switch costs. No moderating effects were observed for the positive mood induction that was low in appetitive motivation. In contrast, positive mood that was high in appetitive motivation was found to increase switch costs in both switch conditions, but only for those with a higher EBR at baseline. Therefore, this suggests that a general increase in effortful control or stability may have occurred only as a result of this induction only for those with a higher EBR at baseline. This is surprising considering the lack of a quadratic or linear relationship observed between EBR and switch costs in the neutral induction. However, it may be the case that the sample size was not large enough to provide enough power for a quadratic relationship to be detected in this analysis.

6.5.3. Conclusions

To summarise, appetitive motivation was not found to moderate the effect of positive mood on switch costs in the present study. However, there was a trend towards greater flexibility (at the cost of distractibility) in the low appetitive condition (i.e., perseveration switch costs were decreased and distraction switch costs were increased). This was in line with hypotheses and previous work finding the same pattern of results when examining the influence of transient emotional responses on this paradigm (Liu & Wang, 2014). This also provides support for suggestions of the motivational intensity model that only positive affect low in appetitive motivation results in greater flexibility (Gable & Harmon-Jones, 2010). However, the pattern of results observed in the present study were only trends and did not reach statistical significance. Therefore, it was suggested that the effects of more enduring mood states on flexibility in cognitive control may be weaker compared to the transitory, although temporarily tightly coupled with task demands, emotional responses induced in previous studies (e.g., Liu & Wang, 2014).

It was also hypothesised that positive mood high in appetitive motivation would result in reduced flexibility (i.e., greater stability) (i.e., switch costs were expected to be increased in the perseveration condition, but decreased in the distraction condition). However, switch costs appeared to be increased in both the perseveration and distraction switch conditions, suggesting that this had a general detrimental effect on performance. This is not in line with suggestions of the motivational intensity model (Gable & Harmon-Jones, 2010), that positive affect high in appetitive motivation results in greater stability. Interestingly, it is also not in line with the reward-as-motivation hypothesis either, which suggests that rewards or appetitive goals must be dependent on performance to enhance stability in cognitive control (Goschke & Bolte,

2014). Therefore, it was suggested that the more enduring mood induction may not have resulted in patterns of switch costs in line with greater effortful control and stability as positive affect high in appetitive motivation did not occur in close temporal proximity to task demands.

The close temporal coupling of the (positive) affective stimuli to task demands in previous studies (i.e., those using briefly presented affective images or reward incentives prior to each trial) may have facilitated the active maintenance of *task-relevant* contextual information. It was speculated that (as positive affect was more temporally remote to task demands in the present study) this may have served only to increase effortful control and working memory load, with no benefit to specific demands of the task. It was also speculated that, during times of greater demands on cognitive control (i.e., attentional switches), this increased load may reduce cognitive control more generally and impair performance across both switch conditions (cf. the association between greater working memory capacity and better performance across both switches, Tharp & Pickering, 2011). Interestingly, however, there were also indications that high appetitive mood was associated with increased stability (reduced distractor compatibility effects) during lower cognitive load (i.e., pre-switch trials).

Chermahini and Hommel (2012) found that EBR was increased for a positive mood induction, which was assumed to be low in appetitive motivation, which was suggested to reflect an increase in D2 dopamine activity in the basal ganglia (Frank & O'Reilly, 2006). However, in the present study, EBR was found to be increased during only the high appetitive induction (in line with findings from Study 2), suggesting that this reflects an increase in D1 dopamine activity in the prefrontal cortex (Durstewitz & Seamans, 2008). Interestingly, EBR was also found to be positively related to distractor inhibition, providing further support for this suggestion. However, EBR was not found to be related to or moderate switch costs in the neutral condition, which was not in line with previous findings (Dreisbach et al., 2005; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011). However, those with a higher EBR were found to have increased switch costs following the induction, suggesting a possible U-shaped relationship with effortful control and general stability.

7. Study 5 – Positive mood, stability in cognitive control, and spontaneous eye blink rate: The influence of appetitive motivation

7.1. Abstract

The AX-CPT can be used to assess that balance between flexibility and stability in cognitive control. This requires participants to categorise a target stimulus, based on a previously presented probe stimulus. Flexibility is demonstrated by enhanced performance on 'AY trials' and attenuated performance on 'BX trials'. Positive affect has been found to reflect greater flexibility, in terms of a lower error rate and/or faster RTs on AY trials, and the opposite pattern on BX trials (e.g., Dreisbach, 2006). In contrast, reward incentives result in faster RTs on both trial types, suggesting greater effortful control, as well as reduced error rate on AY trials, suggesting reduced flexibility (Chiew & Braver, 2013). The present study examined the influence of positive mood states (c.f., briefly presented reward cues) that were high and low in appetitive motivation on the AX-CPT. An additional aim was also to examine the influence of these positive mood states on EBR, and the relationship between EBR and performance.

Sixty participants took part in a laboratory-based experimental study and were randomly assigned to a mood condition. Participants completed a neutral, high appetitive, or low appetitive mood induction, using the same stimuli as Studies 1, 2, 3, and 4. Participants completed the 12-PACS (Yik et al., 2011) to measure positive affect at pre- and post-induction timepoints, and EBR was measured during the induction period using electrooculography. Following the post-induction measure of affect, the AX-CPT was completed.

ANOVAs demonstrated no effect of low appetitive positive mood on RTs, but error rate was lower on AY trials, suggesting greater flexibility (i.e., in line with the motivational intensity model). In contrast, high appetitive positive mood resulted in slower RTs and lower error rates across trial types, suggesting a higher response threshold (i.e., the prioritisation of accuracy over speed), which may reflect a more focused and cautious response style (as opposed to "stability" in cognitive control). ANOVAs demonstrated that mood condition had no effect on EBR, which may have been due to the use of a between-subjects design (i.e., pre-existing differences masking effects). Regression analyses demonstrated EBR was not differentially related to AY vs. BX trials, and ANOVAs demonstrate that EBR did not moderate AX-CPT performance or moderate the influence of mood on performance.

7.2. Introduction

Cognitive control is proposed to govern an antagonistic balance between flexibility and stability, which results in context-dependent costs and benefits for goal-directed behaviour (Goschke, 2000). Specifically, whilst updating of working memory contents and the flexible shifting of attentional focus is argued to be beneficial for switching goals, it may be costly in terms of resulting in increased distraction. However, the stabilisation of working memory representations is argued to be beneficial when shielding active goals from interference, but is costly in terms of increased perseveration (Goschke & Bolte, 2014). Therefore, Studies 3 and 4 of the current research examined the influence of positive mood on a set-shifting paradigm, which was designed by Dreisbach and Goschke (2004) to examine the divergent costs and benefits of flexibility in cognitive control. However, due to the theorised antagonistic relationship between flexibility and stability in cognitive control, it may be expected that positive mood also influences stability (i.e., decreases active maintenance of representations in working memory and, conversely, facilitates greater flexibility) in cognitive control. Therefore, the influence of positive mood on stability in cognitive control is the focus of the present study.

7.2.1. Positive Mood and Stability

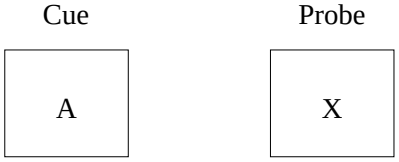
The influence of positive mood has been examined in relation to performance on working memory tasks. For example, performance on simple working memory span tasks (i.e., recall of digits presented sequentially) has been found to be attenuated following positive mood inductions (Martin & Kerns, 2011). However, performance on a complex operation span task (i.e., the recall a series of words presented, whilst completing arithmetic problems in the intervening period), was found to be enhanced due to a positive mood induction (Yang et al., 2013). Although these results seem to suggest that positive mood does not consistently impair or enhance working memory performance, this could be due to differences in the tasks that were used. Specifically, the complex span task, used by Yang et al. (2013), involves additional processes (e.g., flexible shifting between processing and storage when performing the concurrent arithmetic task), which are not required in the simple span task used by Martin and Kerns (2011) (Lépine et al., 2005). Therefore, this could account for divergent findings between these studies.

The AX Continuous Performance Task (AX-CPT; Servan-Schreiber et al., 1996) allows a more detailed assessment of the working memory processes associated with stability in cognitive control. Participants are presented with a cue (A or B), which, after a delay period, is followed

by the presentation of a probe (X or Y). A target response key is pressed on AX trials, when the probe X follows the presentation of the cue A. A non-target response key is pressed on other trials, which can be BX, AY, or BY trials. However, AX trials are manipulated to occur on 70% of trials, which creates a high expectation for probe X to follow the cue A. Therefore, due to the expectation of an X probe, active maintenance of the A cue (i.e., greater stability in cognitive control) is detrimental to performance on AY trials, as this is associated with an incorrect response. However, active maintenance of the B cue on BX trials (i.e., greater stability in cognitive control) is beneficial to performance, as response preparation is biased towards the correct response. The task design is illustrated in Figure 7.1, and performance is assessed by measuring RTs and error rates across the distinct trial types.

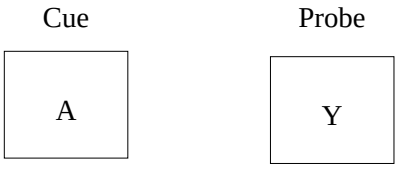
To examine the effect of positive affect on the AX-CPT, Dreisbach (2006) briefly presented positive or neutral images prior to each trial on this paradigm. For trials preceded by positive images, participants had slower RTs on BX trials, and a lower error rate on AY trials, suggesting that positive affect reduced stability in cognitive control. This is further supported by the finding that the influence of positive affect was more pronounced when the interval between the cue and probe was extended, and when distractor letters were presented during this period – presumably increasing the active maintenance demands of the task. In addition, van Wouwe et al. (2011) compared performance on the AX-CPT for positive and neutral mood inductions, in which participants watched film clips prior to completing the task. Although no effect was observed for RTs, participants were found to make fewer errors on AY trials following the positive induction. Therefore, these studies both provide evidence to suggest that stability in cognitive control may be reduced as a result of positive affect.

AX Trial



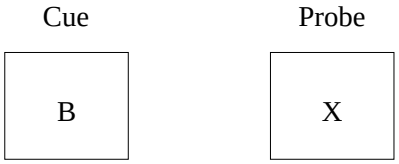
Occur on 70% of trials, creating high expectation for probe X to follow the cue A

AY Trial



Maintenance of cue A is detrimental to performance as expectation of X probe

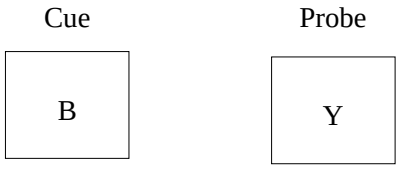
BX Trial



Maintenance of cue B is beneficial as response preparation is biased towards correct response

(despite interference from conflicting X probe)

BY Trial



Maintenance of cue B is beneficial as response preparation is biased towards correct response

(despite interference from conflicting X probe)

Figure 7.1. *Cue-probe conditions of the AX-CPT. AY trials demonstrate the costs of active maintenance, whilst BX trials (and to some extent also BY trials) demonstrate the benefits of active maintenance.*

7.2.1.1. Motivational Intensity Model

The motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognition depends on motivational intensity. This is such that positive affect low in appetitive motivation is argued to result in broader cognition, which is suggested to be beneficial for building personal resources in the absence of appetitive goals (Fredrickson, 1998). In contrast, positive affect high in appetitive motivation is argued to result in narrower cognition, which is beneficial for focusing on the pursuit of rewards or appetitive goals. This model was originally supported by studies demonstrating the moderating effect of motivational intensity in relation to the influence of positive affect on attentional scope (e.g., Gable & Harmon-Jones, 2008b). However, Liu and Wang (2014) recently found that this effect may also apply to the balance between flexibility and stability in cognitive control. Using Dreisbach and Goschke's (2004) set-shifting paradigm, it was demonstrated that positive affect low in appetitive motivation resulted in greater flexibility, whilst this was found to be reduced (i.e., reflecting greater stability) for positive affect high in appetitive motivation.

7.2.2. Reward and Stability

Other studies have examined the effect of reward incentives on the AX-CPT. For example, Locke and Braver (2008) found that offering performance-based reward incentives resulted in faster RTs on all trials (i.e., compared to trials where no incentive was offered). However, no difference in error rates was observed, other than for an increase on AY trials (i.e., suggesting greater stability in cognitive control). A decrease in RTs across all cue-probe conditions was suggested to reflect the facilitation of task preparation due to increased active maintenance of contextual information (i.e., greater stability) (Chiew & Braver, 2013). However, this was also suggested to result in an increase in error rate only on AY trials, as this is the only cue-probe condition for which enhanced maintenance of the cue is detrimental to performance. This pattern of results – a decrease in RTs across all cue-probe conditions, but an increase in error rates only on AY trials – has been replicated in three further studies examining the effect of performance-based reward incentives on the AX-CPT (Chiew & Braver, 2013, 2014; Frober & Dreisbach, 2014).

Two of the studies examining the effect of reward incentives on the AX-CPT (i.e., Chiew & Braver, 2014; Frober & Dreisbach, 2014), have also examined the influence of positive affect (i.e., within the same paradigm) by presenting positive images prior to each trial, as opposed to cues indicating that reward incentives are available. Frober and Dreisbach (2014) found that

positive affect resulted in fewer errors and faster RTs only on AY trials. This suggests that stability in cognitive control was reduced as a result of positive affect (presumably low in appetitive motivation), which is in line with those studies outlined above (i.e., Dreisbach, 2006; van Wouwe et al., 2011). Furthermore, the same pattern of results was found for reward incentives that were not contingent on task performance (i.e., offered to participants regardless of performance). However, Chiew and Braver (2014) found that positive affect resulted in a similar pattern of results as reward incentives, suggesting greater stability in cognitive control (i.e., RTs were faster and there were fewer errors on all trial types, other than for AY trials, as error rate was increased and RTs were slower).

Chiew and Braver's (2014) findings that positive affect resulted in a similar pattern of results as reward incentives, may not be in line with previous studies due to differences in their methodology compared to other studies. For example, Frober and Dreisbach (2014) used distractors during cue-probe intervals, which may increase the active maintenance demands of the task, and has been demonstrated to result in more pronounced effects (Dreisbach, 2006). Chiew and Braver (2014) manipulated affect by presenting positive images prior to each trial. In contrast, participants watched affective video clips prior to the completion of the task, in addition to viewing images prior to each trial, in Frober and Dreisbach's (2014) study. However, although these methodological differences may have weakened the effect of positive affect on AY and BX trials, it does not explain why opposite effects were observed by Chiew and Braver (2014). One possibility could be that there were differences in the motivational intensity of the images presented to induce positive affect compared to other studies, as description of images is vague in both studies.

7.2.2.1. Reward-as-Motivation Hypothesis

Findings that reward incentives generally result in greater stability in cognitive control led to the reward-as-motivation hypothesis (Goschke & Bolte, 2014), which suggests that cues for potential rewards signal that an exploitive mode of behaviour is required. This is proposed to increase motivation to engage in effortful control, optimising task performance, and maximising the likelihood of obtaining the reward (Aston-Jones & Cohen, 2005). Therefore, potential rewards are proposed to facilitate greater stability in cognitive control, as preparatory maintenance of contextual information occurs in the anticipation of interference (Braver et al., 2007). However, positive affect that is not contingent on task performance is suggested to result in greater flexibility (i.e., reduced stability) in cognitive control, allowing the transient

activation of contextual information by bottom-up inputs. Within this account, positive affect is proposed to signal a safe and comfortable environment, indicating to the organism that effortful control is not currently required, which allows this to be conserved.

7.2.3. Neurobiological Mechanisms

Reward incentives are proposed to result in greater stability in cognitive control due to an increase in sustained activity in the prefrontal cortex, which facilitates the active maintenance of goal-relevant information (Braver, 2012). Specifically, it is suggested that an increase in dopamine levels in the prefrontal cortex activates tonic D1 receptor neurons, enabling the stabilisation of representations in working memory (Durstewitz & Seamans, 2008). This is supported by findings from genetic studies, such as those examining performance on the AX-CPT in relation to the COMT Val158Met polymorphism, which is associated with prefrontal dopamine degradation. For example, it has been found that those individuals with Met alleles (i.e., greater dopamine availability) made more errors on AY trials, indicating greater stability in cognitive control, compared to those with Val alleles (i.e., lower dopamine availability) (Leung, McClure, Siever, Barch, & Harvey, 2007). This is also in line findings from a separate study, which demonstrated that error rates on BX trials, indicating greater stability in cognitive control (i.e., maintenance of the B cue is beneficial) were reduced for individuals with Met (compared to Val) alleles (Lopez-Garcia, Young Espinoza, Molero Santos, Marin, & Ortuno Sanchez-Pedreno, 2012).

Other studies have suggested that dopamine activity in the basal ganglia may also be relevant to performance. For example, patients with schizophrenia (i.e., associated with elevated dopamine levels in the basal ganglia) have been demonstrated to have reduced error rates on AY trials, indicating attenuated stability in cognitive control (Lopez-Garcia et al., 2012). In contrast, patients with Parkinson's disease (i.e., associated with decreased dopamine levels in the basal ganglia) have reduced error rates on BX trials, indicating greater stability in cognitive control (Moustafa, Sherman, & Frank, 2008). This may be explained by the suggestion that an increase in dopamine activity in the basal ganglia may be related to flexibility (i.e., reduced stability) in cognitive control. Specifically, Frank and O'Reilly (2006) proposed that an increase in dopamine levels in this area activates D1 receptor neurons, which facilitates information entry into working memory, and suppresses D2 receptor neurons, which inhibits the flow of information. Therefore, this is suggested to enhance flexibility by facilitating updating and the flexible switching of attention between representations.

Based on this, it may be suggested that positive affect results in an increase in dopamine in the basal ganglia, facilitating flexibility in cognitive control, which is in line with findings of enhanced performance on set-shifting paradigms for positive affect (Dreisbach & Goschke, 2004). Taking into account the antagonistic relationship with stability in cognitive control, this may also explain findings of impaired performance on the AX-CPT for positive affect (Dreisbach, 2006). In contrast, reward incentives may be suggested to result in an increase in dopamine in the prefrontal cortex, facilitating stability (Locke & Braver, 2008). Reward incentives have also been found to result in impaired performance on Dreisbach and Goschke's (2004) set-shifting paradigm (Muller, Dreisbach, Goschke, et al., 2007), which may again reflect an antagonistic relationship between flexibility and stability in cognitive control. Therefore, performance on the AX-CPT may be suggested to depend on the reciprocal relationship between dopamine activity in the prefrontal cortex and basal ganglia, which can be moderated by positive affect and reward incentives (Cools & D'Esposito, 2011).

7.2.4. Present Study

It is currently unclear whether the effect of positive affect on stability in cognitive control is moderated by motivational intensity. Reward incentives have been demonstrated to enhance stability on the AX-CPT, whilst positive affect reduces stability (e.g., Frober & Dreisbach, 2014). The reward-as-motivation hypothesis suggests that this is due to reward incentives increasing motivation to engage in effortful control (Aston-Jones & Cohen, 2005), whilst positive affect that is unrelated to performance is proposed to signal a safe environment to conserve control and flexibly pursue alternative goals. This assumes that greater stability in cognitive control will occur when an individual is actively pursuing an appetitive goal, whereas positive affect, other than when directly associated with performance-based reward, will result in greater flexibility (i.e., reduced stability). Alternatively, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the active pursuit of an appetitive goal is not necessary for greater stability, and that this occurs due to the experience of positive affect high in appetitive motivation. It also suggests that it is specifically positive affect low in appetitive motivation that results in greater flexibility in cognitive control.

Although appetitive motivation has been found to moderate the effect of positive affect on Dreisbach and Goschke's (2004) set-shifting task (i.e., Liu & Wang, 2014), this has not previously been explored in relation to performance on the AX-CPT. One recent study conducted by Wacker (2017) did attempt to examine this using positive mood inductions that

could be described as high and low in appetitive motivation. Error rates were found to be very low and were not suitable for analysis. Despite this, RTs were found to be numerically slower for AY trials, and faster for BX trials, following the high (compared to low appetitive) mood induction. However, these effects did not reach statistical significance, which could be attributable to the mood inductions failing to produce the expected changes to affect, suggesting a lack of effectiveness. Therefore, the present study aims to examine the moderating role of appetitive motivation in relation to the influence of positive mood on the AX-CPT. To do this, performance on AY and BX trials will be examined after positive mood inductions that are high and low in appetitive motivation, and after a neutral mood induction.

In line with the motivational intensity model (Gable & Harmon-Jones, 2010), it is hypothesised that positive mood low in appetitive motivation will result in reduced stability in cognitive control, whilst greater stability will occur for positive mood high in appetitive motivation. It is assumed that Chiew and Braver's (2014) findings (i.e., greater stability on the AX-CPT for positive affect) were due to issues with the design of this study. Therefore, it is expected that positive affect low in appetitive motivation will result in decreased error rates and/or faster RTs on AY trials, but slower RTs and/or an increased error rate on BX trials (i.e., in line with findings from (Dreisbach, 2006; Frober & Dreisbach, 2014; van Wouwe et al., 2011). However, positive affect high in appetitive motivation is expected to result in faster RTs across all trial types (or at least for AY trials), but an increased error rate on only AY trials (i.e., in line with findings of (Chiew & Braver, 2013, 2014; Frober & Dreisbach, 2014; Locke & Braver, 2008).

Reward incentives have been suggested to enhance stability in cognitive control due to an increase in activity in the prefrontal cortex (Braver, 2012). Specifically, this increase in activity is suggested to reflect the stimulation of tonic D1 dopamine receptor neurons, which facilitates the stabilisation of working memory representations (Durstewitz & Seamans, 2008). Although previous studies have linked performance on the AX-CPT to individual differences in prefrontal dopamine activity (Leung et al., 2007; Lopez-Garcia et al., 2012), there is little evidence demonstrating that this activity may underlie the influence of reward incentives on this paradigm. Furthermore, an increase in prefrontal dopamine activity has been suggested to occur during positive affect high in appetitive motivation, whilst positive affect low in appetitive motivation is suggested to be related to separate neural substrates (Depue & Collins, 1999). Therefore, it could be suggested that positive mood high in appetitive motivation may enhance stability on the AX-CPT due to an increase in dopamine activity in the prefrontal cortex (i.e., stimulating tonic D1 receptor neurons).

Other studies have suggested that individual differences in dopamine activity in the basal ganglia influence performance on the AX-CPT (Lopez-Garcia et al., 2012; Moustafa et al., 2008). Models of cognitive control suggest that an increase in dopamine activity in the basal ganglia facilitates updating and the flexible shifting of attention (Frank & O'Reilly, 2006). Therefore, this activity may be suggested to underlie previous findings that positive affect (i.e., which presumably is low in appetitive motivation) results in attenuated flexibility on the AX-CPT (Dreisbach, 2006; Frober & Dreisbach, 2014; van Wouwe et al., 2011). However, there is no evidence implicating dopamine activity in the basal ganglia as underlying the influence of positive affect on the AX-CPT. Therefore, albeit indirectly, the present study also aims to explore the neurobiological mechanisms, in relation to dopamine activity, that may underlie the possible differential effect of positive mood states that are high and low in appetitive motivation on stability in cognitive control. To do this, EBR during positive mood inductions will be compared to the neural mood induction.

It has widely been suggested that EBR may specifically reflect the activity of D2 dopamine receptor neurons in the basal ganglia, especially when this is assessed at baseline (Jongkees & Colzato, 2016). However, increases in D1 and D2 dopamine activity have both been found to result in an increase in EBR following pharmacological manipulations (e.g., Elsworth et al., 1991). Interestingly, the results of Study 2 and 4 of the current research found that EBR was increased only following the positive mood induction that was high in appetitive motivation, which suggests that changes in EBR may reflect D1 dopamine activity in the prefrontal cortex. Furthermore, EBR was found to decrease as a result of the positive mood induction that was low in appetitive motivation, in line with a reciprocal relationship between dopamine activity in the prefrontal cortex and basal ganglia underlying cognitive control (Cools & D'Esposito, 2011). Therefore, it is hypothesised that EBR will be greater during the positive mood induction that is high (vs. low) in appetitive motivation.

The present study will also examine the relationship between EBR and performance on the AX-CPT, as increased stability may be associated with an increase in EBR, if this is assumed to reflect dopamine activity in the prefrontal cortex. Due to the reciprocal relationship that is suggested to exist between dopamine activity in the prefrontal cortex and the basal ganglia (Cools & D'Esposito, 2011), reduced stability may also be associated with decreases in EBR. However, the relationships between dopamine activity in the prefrontal cortex and stability (and in the basal ganglia and flexibility) in cognitive control, have previously been demonstrated to be non-linear, reflecting an inverted U-shape (Cools & D'Esposito, 2011;

Floresco, 2013). Therefore, the present study will also examine the possibility that the relationships between EBR and AX-CPT performance may also be non-linear. It is hypothesised that there will be a negative (or inverted U-shaped) quadratic relationship between EBR and RTs and/or error rates on AY trials, but a positive (or U-shaped) quadratic relationship for RTs and/or error rates on BX trials.

EBR has been demonstrated to moderate performance on Dreisbach and Goschke's (2004) set-shifting task (e.g., Dreisbach et al., 2005), such that performance is enhanced for those with a higher EBR. Therefore, the present study will also compare performance on the AX-CPT for individuals with a higher or lower EBR, to examine whether EBR moderates performance on the pertinent cue-probe conditions, and thus influences stability in cognitive control on this paradigm. Those individuals with a higher EBR are hypothesised to display greater stability in cognitive control (i.e., faster RTs on AY trials and less errors on BX trials) compared to those with a lower EBR. It may also be the case that those with a lower EBR display attenuated stability (i.e., slower RTs and/or more errors on AY trials, as well as faster RTs and/or less errors on BX trials) compared to those with a higher EBR. Therefore, this would reflect greater stability for those with a higher EBR, and possibly reduced stability (and greater flexibility) for those with a lower EBR. Furthermore, this will be followed by exploration of whether EBR moderates the influence of positive mood on performance of the AX-CPT.

7.2.5. Aims and Hypotheses

1. To examine the moderating role of appetitive motivation in relation to the influence of positive mood on the AX-CPT. To do this, performance on AY and BX trials will be examined after positive mood inductions that are high and low in appetitive motivation, and after a neutral mood induction.

i) It is hypothesised that positive mood low in appetitive motivation will result in reduced stability in cognitive control (decreased error rate and/or faster RTs on AY trials, but slower RTs and/or an increased error rate on BX trials).

ii) It is hypothesised that positive mood high in appetitive motivation will result in greater stability in cognitive control (faster RTs across all trial types, or at least for AY trials, but an increased error rate on only AY trials).

2. To explore the neurobiological mechanisms that may underlie the possible differential effect of positive mood states that are high and low in appetitive motivation on stability in cognitive control, using an indirect physiological measure of dopamine activity (i.e., EBR).

i) It is hypothesised that EBR will be greater during only the positive mood induction that is high in appetitive motivation.

ii) It is hypothesised that there will be a negative (or inverted U-shaped) quadratic relationship between EBR and RTs and/or error rates on AY trials, but a positive (or U-shaped) quadratic relationship for RTs and/or error rates on BX trials.

iii) It is hypothesised that those individuals with a higher EBR will display greater stability in cognitive control (i.e., faster RTs on AY trials and less errors on BX trials) compared to those with a lower EBR.

iv) The moderating effect of EBR on the influence of positive mood on AX-CPT performance will also be explored.

7.3. Method

7.3.1. Participants

Sixty undergraduate Psychology students (7 males, 55 females) aged between 18 and 43 years (M = 21.08 years, SD = 5.24) were recruited from a London university, and received course credit for participation. Participants were randomly assigned to either a neutral (n = 20), high appetitive (n = 20), or a low appetitive mood condition (n = 20). None of the participants had any problems with their colour vision. The study was approved by the University Research Ethics Committee, and all participants provided informed consent at the start of the study, and were fully debriefed at the end of the study.

7.3.2. Measures

7.3.2.1. Mood Induction

Participants completed a mood induction to induce either a neutral mood, positive mood high in appetitive motivation, or positive mood low in appetitive motivation. The vignettes, music, and procedure were the same as those used as in Study 4, (although there was no mood booster session as the task in the present study was much shorter).

7.3.2.2. Positive Affect

As was the case in Study 2, 3, and 4, an adapted version of the 12-Point Affect Circumplex Scale (12-PACS; Yik et al., 2011) was used to measure positive affect, with the adjective format and visual analogue response scale. Focus was again on the Activation-Pleasure and Deactivation-Pleasure quadrants of the circumplex, with scores collapsed to form Activated Positive Affect and Deactivated Positive Affect factors. Internal consistency for the deactivated positive affect composite score was good ($\alpha > .72$), but this was much lower for activated positive affect ($\alpha = .57$, $\alpha = .54$). Therefore, analyses with activated positive affect will be conducted separately for each pair of adjectives.

7.3.2.3. AX-Continuous Performance Task

To assess stable maintenance participants completed the AX Continuous Performance Task (AX-CPT; Servan-Schreiber et al., 1996), which was programmed using Matlab R2014. On each trial, participants were presented with a cue letter that, after a delay period, was followed by the presentation of a probe letter. A target response key was pressed when the probe letter X followed the presentation of cue letter A, which is referred to as an AX trial. A non-target response key was pressed on BX trials (probe letter X follows the presentation of the cue letter B), on AY trials (probe letter Y follows the presentation of the cue letter A), and on BY trials (probe letter Y follows the presentation of the cue letter B). Target AX trials were manipulated to occur on 70% of trials, creating a high expectation for probe X to follow the cue A, whilst non-target (AY, BX, and BY) trials occur on 10% of trials each. In line with other studies, a modified version of the AX-CPT was used, in which distractor letters were presented during the delay period between cue and probes, to enhance the maintenance demands of the tasks (Dreisbach, 2006; Frober & Dreisbach, 2014). Accuracy and response times were analysed for each trial type, to determine the costs of maintenance (AY trials) and the benefits of maintenance (BX trials).

The actual letters ‘A’ and ‘X’ were used in AX trials, whilst B cues, Y probes, and distractor letters were randomly selected from the letters 'B' ,'D' ,'E' ,'F', 'G' ,'M' ,'P' ,'S' ,'U', 'Z', without repetitions of letters within a trial (Dreisbach, 2006). To facilitate discrimination between cue/probe letters and distractors, cue/probe letters were always pink, whilst distractor letters were always black (see Figure 7.2)

Figure 7.2. *Example sequences for cue-probe conditions of the AX-CPT. Figure is adapted from Dreisbach (2006).*

On each trial, cue letters were presented for 300 ms, followed by a blank screen presented for 200 ms. Three distractor letters were then consecutively presented for 300 ms each, followed by a blank screen for 200 ms. The probe letter was then presented and remained on the screen until a response was made, followed by an inter-trial interval of 500 ms. Participants were required to press the left or right response key for target and non-target responses. Feedback was only provided when an incorrect response was made, such that the word 'Error' was presented on the screen for 1000 ms prior to the inter-trial interval. A total of 200 trials were completed in total, with 140 AX trials, and 15 AY, BX, and BY trials presented in a randomised order. Participants were instructed to respond as quickly and as accurately as possible and completed 20 practice trials prior to the main experimental block.

7.3.2.4. EBR

Vertical electrooculogram (EOG) recording was used to assess EBR as a physiological marker of dopamine activity. Eye blinks are detected by examining voltage differences between electrodes placed above and below the eye. Electrodes were placed approximately 3 cm above and 2 cm below the left eye, as measured from the centre of the pupil, with a ground electrode placed in the centre of the forehead, and a reference on the left ear (Barbato et al., 2012). Horizontal EOG was also recorded with the placement of an electrode in the lateral external canthi approximately 1 cm from the left eye.

EOG signals were recorded using a 19-channel Mitsar-EEG-201 system with a sampling rate of 500 Hz, and WinEEG v2.103.70 was used to analyse data. In line with previous studies, a 0.5-15 Hz band pass filter was applied, and eye blinks were visually determined based on sharp increases in the amplitude of the waveform (greater than 100 μV) occurring for less than 500 ms (Byrne et al., 2015; Nakanishi et al., 2012). Increases in the amplitude of the waveform were not counted as eye blinks when consistent with horizontal eye movements (Barbato et al., 2012).

The first minute was considered a period of adaptation and not included in analysis (Borges et al., 2010). Therefore, eye blink frequency was counted in the following 4min, which were divided into 4 x 60sec periods, allowing the mean number of eye blinks to be calculated (Dreisbach et al., 2005). In line with previous studies, registration always occurred during daylight hours, based on findings that EBR is stable during the day (Barbato et al., 2000). Inter-reliability for EBR was found to be good (r = .99, p < .001), for a randomly selected 10% sample of the data.

7.3.3. Procedure

Upon arrival participants were seated in the laboratory and completed paper and pencil versions of the 12-PACS. Afterwards, they were seated at a computer where EOG electrodes were placed, followed by practice trials for the AX-CPT. Once completed, participants had the opportunity to ask any questions before the researcher left the room. The computerised mood induction was then completed whilst EOG was recorded, which was followed by the second version of the 12-PACS. Finally, the AX-CPT was completed, after which participants left the laboratory. The order of 12-PACS versions was counterbalanced within mood conditions, and the experiment lasted approximately one hour.

7.4. Results

7.4.1. Data Screening

Data screening used the techniques and followed procedures outlined in the previous chapters. This indicated that all assumptions were met, other than where specified below.

Therefore, data was assumed to be approximately normally distributed (i.e., a Gaussian distribution was observed on histograms) and there were no outliers (i.e., values were not found to be 1.5 interquartile ranges from the median or to have a z-score 3.29 standard deviations above the mean). There was also approximately equal variance between groups (i.e., Levene's tests were non-significant), and the assumption of sphericity was not found to be violated (i.e., Mauchley's tests of sphericity were found not to be significant).

7.4.2. Mood Manipulation Check

To examine the effectiveness of the mood manipulation, two separate 3 (mood condition: neutral/low appetitive/high appetitive) by 2 (time: pre-induction/post-induction) mixed design ANOVAs were conducted with activated and deactivated positive affect as the dependent variables.

7.4.2.1. Activated Positive Affect

For activated positive affect, results of the ANOVA demonstrated that there were significant main effects of time and mood condition [F's $\geq$ 5.90, p's $\leq$ .018, $\eta^2p \geq 0.09$]. However, the pertinent time and mood condition interaction was also significant [$F(2,57) = 5.25$, $p = .008$, $\eta^2p = 0.16$].

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine the differences in activated positive affect between pre- and post-induction timepoints within the mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to three multiple comparisons (α = .016) and the mean scores are displayed in Figure 7.3.

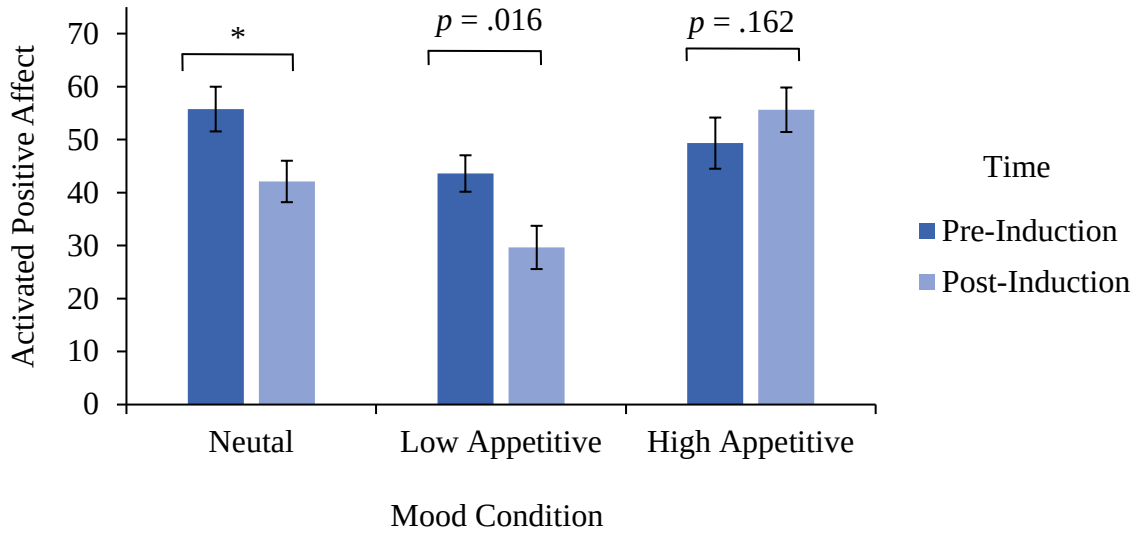


Figure 7.3. *Activated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for three multiple comparisons * p < .013.*

Figure 7.3 demonstrates that, for the high appetitive condition, although there was an increase in activated positive affect [(*M* = 49.33, *SD* = 18.80) to (*M* = 55.63, *SD* = 21.59)], this did not reach significance [*t*(19) = 1.01, *p* = .162, *d* = 0.31]. In contrast, there was a significant decrease in activated positive affect for the neutral condition [*t*(19) = -2.99, *p* = .004, *d* = -0.75] and the low appetitive condition, [*t*(19) = -3.35, *p* = .016, *d* = 0.35].

As the composite activated positive affect score was somewhat unreliable, differences between pre- and post-induction activated positive affect in the high appetitive condition were examined separately for the two components. An increase in activated positive affect at the post-induction timepoint was found to closer to significance for the energetic/excited component [*t*(19) = 1.42, *p* = .086, *d* = 0.41] compared to the enthusiastic/elated component [*t*(18) = 0.40, *p* = .347, *d* = 0.15].

Therefore, this suggests that there was a trend towards the expected increase in activated positive affect (i.e., for the energetic/excited component) during the mood induction that was high in appetitive motivation.

Finally, to examine pre-existing differences in activated positive affect between mood conditions, a one-way between-subjects ANOVA was conducted at the pre-induction timepoint. This confirmed that there were no differences in activated positive affect between mood condition [$F(2,57) = 2.35$, $p = .194$, $\eta^2p = 0.08$].

7.4.2.2. Deactivated Positive Affect

For deactivated positive affect, results of the ANOVA demonstrated that the main effect of time approached significance [$F(1,57) = 3.72$, $p = .059$, $\eta^2p = 0.06$], whilst the main effect of mood condition was not found to be significant [$F(2,57) = 0.64$, $p = .530$]. However, the pertinent time by mood condition interaction also approached significance [$F(2,57) = 2.71$, $p = .075$, $\eta^2p = 0.09$].

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine the differences in deactivated positive affect between pre- and post-induction timepoints within the mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to three multiple comparisons ($\alpha = .016$) and mean scores are displayed in Figure 7.4.

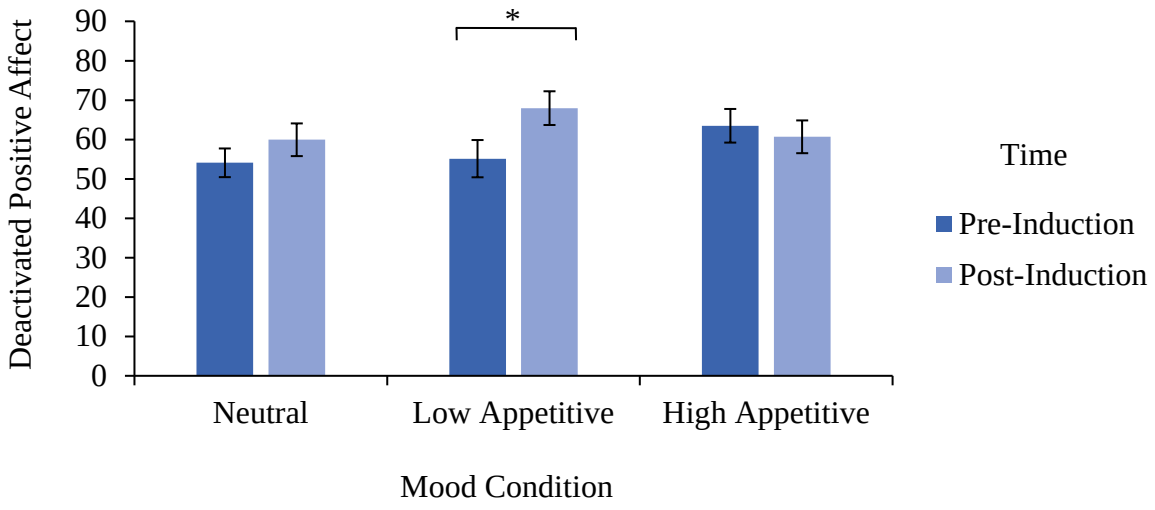


Figure 7.4. *Deactivated positive affect at different time points for each mood condition. Error bars reflect one standard error above and below the mean. Bonferroni correction for three multiple comparisons. * p < .013*

Figure 7.4 demonstrates that, for the low appetitive mood induction, there was a significant increase in deactivated positive affect [$t(19) = 2.65$, $p = .008$, $d = 0.64$], [($M = 55.13$, $SD = 21.13$) to ($M = 67.96$, $SD = 19.13$)]. However, there was no significant difference for the neutral

mood condition [$t(19) = 1.17$, $p = .256$, $d = 0.33$] or high appetitive condition [$t(19) = -0.64$, $p = .532$, $d = -0.03$].

Therefore, this suggests that the mood induction was effective in terms of resulting in the expected increase in deactivated positive affect for only the low appetitive condition.

Finally, to examine pre-existing differences in deactivated positive affect between mood conditions, a one-way between-subjects ANOVA was conducted at the pre-induction timepoint. This confirmed that there were no differences in deactivated positive affect between mood conditions [$F(2,57) = 1.48$, $p = .236$, $\eta^2p = 0.05$].

7.4.3. Effect of Positive Mood on AX-CPT RTs

Incorrect responses were removed from analysis and mean scores were calculated for each cue-probe condition (AX/AY/BX/BY trials).

RTs for all trial types were positively skewed, but using a natural log transformation to correct for this did not change the pattern of results observed in analyses (Harmon-Jones & Amodio, 2012; Whelan, 2008).

One participant in the neutral condition had RT means that were determined to be outliers (high values reflecting slower responses) in each cue-probe condition. These were winsorised to the next nearest value, which did not change the overall results of this analysis (Ghosh & Vogt, 2012).

To examine the effect of mood on AX-CPT RTs, a (cue-probe condition: AX/AY/BX/BY) by 3 (mood condition: neutral/low appetitive/high appetitive) mixed ANOVA was conducted. As Mauchly's test of sphericity was found to be significant for the cue-probe condition, the Greenhouse Geisser procedure was applied to correct for an inflation of Type I error (ε=.80) in this analysis.

7.4.3.1. Main Effect of Cue-Probe Condition

There was a significant main effect of cue-probe condition [$F(2.40,136.57) = 173.76$, $p < .001$, $\eta^2p = 0.75$], so post hoc pairwise comparisons were conducted between cue-probe conditions (AY/AX/BX/BY).

Comparisons showed significant differences between all cue-probe conditions (all p's < .05), although when a Bonferroni correction was applied to control for Type I error due to multiple

comparisons, the comparison between BX and BY conditions was no longer significant (p = .311).

RTs were found to be slowest for AY trials (M = 576.25, SD = 58.29), followed by AX (M = 403.35, SD = 41.48), BX (M = 338.47, SD = 72.77), and then BY trials (M = 576.25, SD = 70.58), in line with findings from previous studies using the AX-CPT (e.g., Frober & Dreisbach, 2014).

7.4.3.2. Main Effect of Mood Condition

As the main effect of mood condition approached significance [$F(2,57) = 2.83$, $p = .068$, $\eta^2p = 0.09$], post hoc tests were conducted to examine pairwise comparisons.

No difference in RTs was found between the neutral and low appetitive condition, or between the low and high appetitive conditions (p's $\geq .649$). However, an increase in RTs for the high appetitive compared to the neutral condition (M = 453.75, SD = 4.47 vs. M = 384.30, SD = 4.47) was found to approach significance (p = .063).

This suggests that participants in the high appetitive condition were slower to respond across trial types on the AX-CPT. This is in contrast to previous studies that have examined the effects of performance-based reward incentives on the AX-CPT (e.g., Frober & Dreisbach, 2014), which found that RTs were faster across all trial types.

7.4.3.3. Cue-Probe by Mood Condition Interaction

The cue-probe by mood condition interaction was not found to be significant [$F(4.79,136.57) = 0.43$, $p = .821$]. To confirm this, planned contrasts using simple effects analysis was conducted with between-subject t-tests. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons ($\alpha = .013$). The means for this analysis are displayed in Figure 7.5.

For the high appetitive condition, Figure 7.5 clearly shows that RTs were slower across all trial types, compared to the neutral condition [t's ≥ 2.00, p's $\leq .027$, d's ≥ 0.63].

For the low appetitive condition, Figure 7.5 demonstrates a similar, but less pronounced, pattern for RTs, and this was found to be further from significance [t's ≤ 1.10, p's $\geq .140$, d's ≤ 0.35].

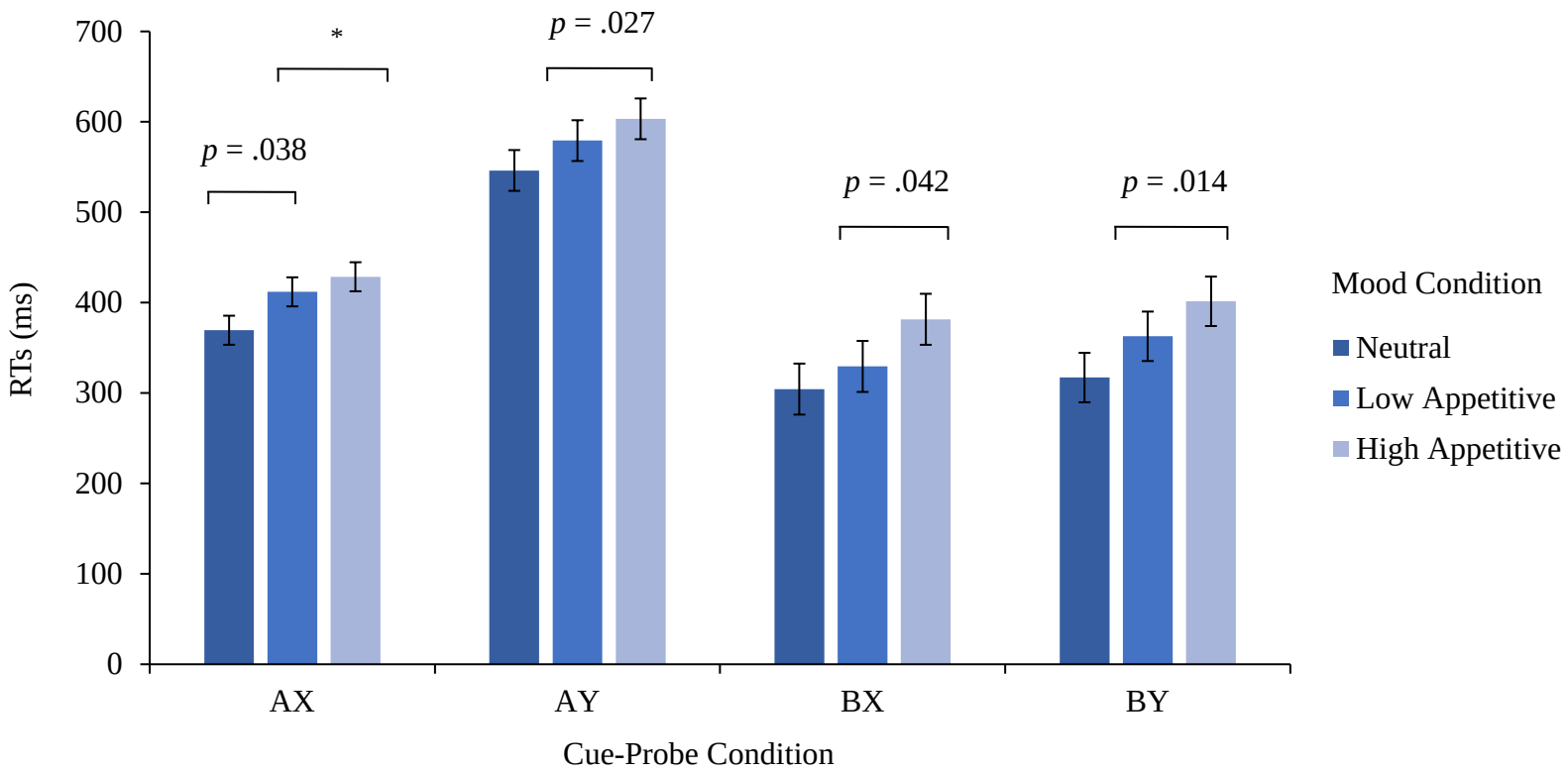


Figure 7.5. *RTs as a function of cue-probe conditions and mood conditions. Error bars reflect one standard error above and below the mean. Bonferroni correction for three multiple comparisons, * $p < .013$.*

Therefore, this suggests that RTs were generally slower as a result of both positive mood inductions, although this was more apparent in the high appetitive condition.

7.4.3.4. Relationships with Positive Affect

The correlations between activated and deactivated positive affect and RTs in the different cue-probe conditions were also explored. This was in relation to both positive affect reported at the post-induction timepoint and changes in positive affect during the mood induction (i.e., post-minus pre-induction positive affect). As RT data was not normally distributed, Spearman's rho was used as the correlation coefficient.

For activated positive affect at the post-induction timepoint, there was some evidence of weak positive relationships with RTs for all trial types, but this was not significant [r_s's $\leq .14$, p's $\geq .275$]. This was also the case when adjectives (i.e., enthusiasm/elation and energy/excitement) were examined separately (r_s's $\leq .20$, p's $\geq .119$).

For change in activated positive affect, there was also some evidence of weak positive relationships with RTs across AX, BX, and BY trials, but this only reached significance for RTs on AY trials [$r_s(60) = .31$, $p = .015$]. Examination of adjectives showed that this was the case only for the enthusiasm/elation adjective [$r_s(58) = .32$, $p = .014$].

For deactivated positive affect, there were no significant relationships with RTs at the post-induction timepoint (r_s's $\leq .09$, p's $\geq .517$) or when change scores were calculated (r_s's $\leq$-.09, p's $\geq .499$).

This suggests that there was only evidence of a relationship between activated (but not deactivated) positive affect and RTs, such that greater activated positive affect (and a greater increase in activated positive affect as a result of the mood inductions) was associated with slower RTs. Although this was evident across cue-probe conditions, it was most pronounced for AY trials.

7.4.4. Effect of Positive Mood on AX-CPT Error Rates

Error rate for AX and BY trials was not determined to reflect a continuous scale with sufficient variance for analysis (most participants had a score of zero). Therefore, mean error rate for these cue-probe conditions was excluded from analysis.

Error rates on all trial types were positively skewed, but using a natural log transformation to correct for this did not change the pattern of results observed in (Harmon-Jones & Amodio, 2012; Whelan, 2008).

There were also three outliers for error data on BX trials, one in the neutral condition and two in the low appetitive condition (both high scores reflecting more errors), and there was one outlier in error data on AY trials in the neutral condition (a high score).

To examine the effect of positive mood on AX-CPT mean error rates, a 2 (cue-probe condition: AY/BX) by 3 (mood condition: neutral/low appetitive/high appetitive) mixed design ANOVA was conducted. Levene's test for homogeneity of variance was significant for BX trials, but this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups, when cell sizes are approximately equal (Zimmerman, 2004).

7.4.4.1. Main Effect of Cue-Probe Condition

The main effect of cue-probe condition was significant [$F(1,57) = 13.76$, $p < .001$, $\eta^2p = 0.19$], such that error rates were greater for AY ($M = 13.25\%$, $SD = 9.53$) compared to BX trials ($M = 7.33\%$, $SD = 8.44$), which is in line with previous studies that have used the AX-CPT (e.g., Frober & Dreisbach, 2014).

7.4.4.2. Main Effect of Mood Condition

The main effect of mood condition was also significant [$F(2,57) = 7.50$, $p = .001$, $\eta^2p = 0.21$], which was further investigated using post hoc pairwise comparisons, with a Bonferroni correction for inflated Type I error.

Error rate was found to be significantly greater for the high appetitive ($M = 14.38\%$, $SD = 6.53$) compared to the neutral condition ($M = 6.38\%$, $SD = 6.53$) ($p = .001$). Error rate was also numerically greater for the low appetitive condition ($M = 10.13\%$, $SD = 6.53$), although this did not reach significance ($p = .133$). There was also no significant difference between the low and high appetitive conditions ($p = .225$).

Therefore, this suggests that error rate was increased as a result of both positive mood inductions, although this was more pronounced for the high appetitive condition.

7.4.4.3. Cue-Probe by Mood Condition Interaction

The cue-probe by mood condition interaction was also not far from significance [$F(1,57) = 2.37$, $p = .103$, $\eta^2p = 0.08$]. Therefore, planned comparisons were conducted using simple effects analysis with independent t-tests. A Bonferroni correction was used to control for inflated Type I error due to the four multiple comparisons ($\alpha = .013$) and the means for this analysis are displayed in Figure 7.6.

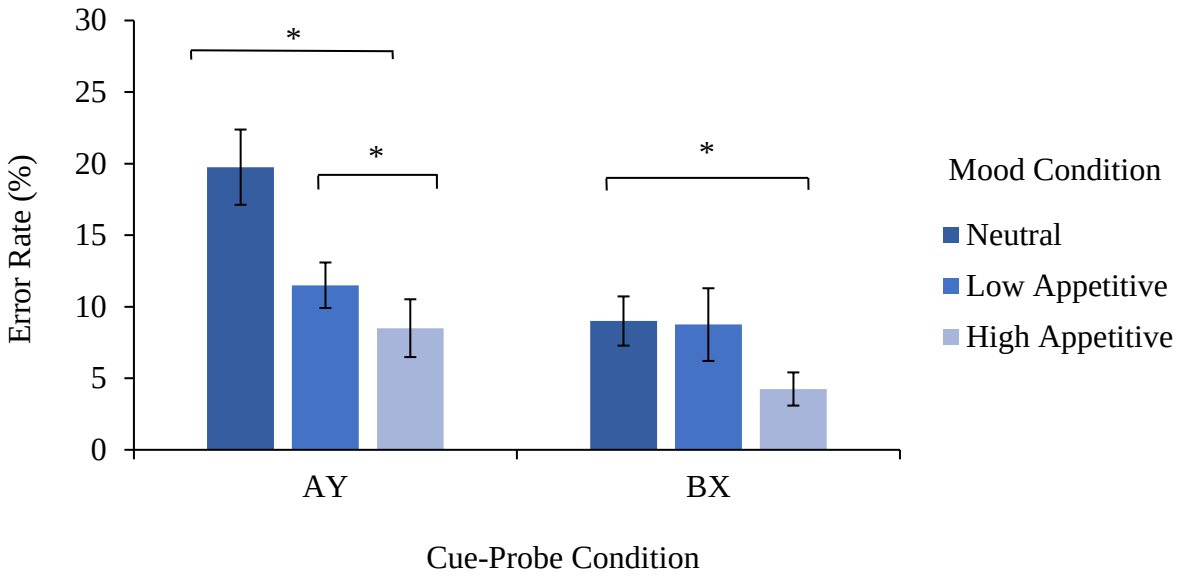


Figure 7.6. *Error rates as a function of cue-probe and mood condition. Error bars reflect one standard error above and below the mean. With Bonferroni correction for three multiple comparisons * p < .013.*

For AY trials, Figure 7.6 demonstrates that error rate was significantly lower in both the high appetitive ($M = 8.50\%$, $SD = 19.75$) and low appetitive ($M = 11.50\%$, $SD = 7.09$) compared to the neutral condition ($M = 19.75\%$, $SD = 11.75$), ($t \geq -2.68$, $p \leq .006$, $d \geq -0.85$).

For BX trials, Figure 7.6 demonstrates that error rate was lower in the high appetitive ($M = 4.25\%$, $SD = 5.20$) compared to the neutral condition ($M = 9.00\%$, $SD = 7.71$), and this effect approached significance [$t(38) = -2.28$, $p = .014$, $d = -0.72$]. However, there was no significant difference between the neutral and low appetitive conditions ($M = 8.75\%$, $SD = 11.34$), [$t(38) = -0.08$, $p = .468$, $d = -0.03$].

Therefore, error rate was found to be reduced across AY and BX trials in the high appetitive condition, but this was only the case for AY trials in the low appetitive condition.

7.4.4.4. Relationships with Positive Affect

The correlations between activated and deactivated positive affect and error rates in AY and BX cue-probe conditions were also explored. This was in relation to both positive affect reported at the post-induction timepoint and changes in positive affect during the mood induction (i.e., post-minus pre-induction positive affect). As error rate data was not normally distributed, Spearman's rho was used as the correlation coefficient.

For activated positive affect at the post-induction timepoint, there was no evidence of a relationship with error rate on either AY or BX trials (r_s's ≤ -.09, p's ≥ .537), which was also the case when adjectives (i.e., enthusiasm/elation and energy/excitement) were examined separately (r_s's ≤ .17, p's ≥ .206).

This was also the case for change in activated positive affect (r_s's ≤ -.13, p's ≥ .318), across both sets of adjectives (r_s's ≤ -.15, p's > .253).

For deactivated positive affect at the post-induction timepoint, there was also no evidence of a relationship with error rate of either AY or BX trials (r_s's ≤ -.15, p's ≥ .253).

Again, this was also the case for change in deactivated positive affect (r_s's ≤ -.11, p's ≥ .406).

7.4.5. Effect of Positive Mood on EBR

EBR could not be determined for three participants (two in the neutral and one in the high appetitive condition), as eyes were closed during the mood induction period. EBR could also not be determined for one further participant in the neutral condition due to excessive noise in the EOG recording, likely reflecting movement artefacts. Therefore, sample size for this analysis was reduced to N = 56 (low appetitive n = 20, high appetitive n =19, and neutral n = 17).

There was one high EBR value in the low appetitive condition that was determined to be outlier, and this was winsorised to the next nearest value.

To examine the effect of mood on EBR, a 3 (mood condition: neutral/low appetitive/high appetitive) way between-subject ANOVA was conducted with EBR as the dependent variable. However, the expected main effect of mood induction was not found to be significant [F(2,53) = 0.14, p = .872, η^2p = 0.01].

Despite the lack of a significant main effect for mood, planned contrasts were conducted using simple effects analysis with independent t-tests, to confirm that mood condition had no effect

on EBR. A Bonferroni correction was used to correct for inflated Type I error due to the two multiple comparisons (α = .025) and the means for this analysis are displayed in Figure 7.7.

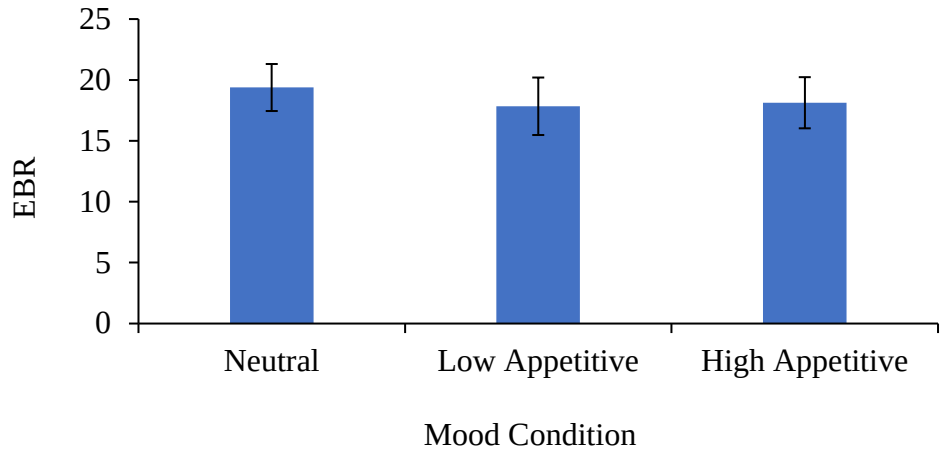


Figure 7.7. *EBR for the different mood conditions. Error bars reflect one standard error above and below the mean.*

Figure 7.7 demonstrates that there were no significant differences in EBR when the neutral condition was compared to the low appetitive condition [$t(34) = -0.50$, $p = .312$, $d = -0.16$], or the high appetitive condition [$t(34) = -0.43$, $p = .334$, $d = -0.11$].

Therefore, this suggests that neither of the positive mood inductions resulted in any change in EBR compared to the neutral induction.

7.4.5.1. Relationships with Positive Affect

The correlations between activated and deactivated positive affect and EBR were also explored, in relation to both positive affect reported at the post-induction timepoint, and changes in positive affect during the mood induction (i.e., post-minus pre-induction positive affect).

For activated positive affect at the post-induction timepoint, there was evidence of a weak positive relationship with EBR, but this did not reach significance [$r(56) = .18$, $p = .186$], which was still the case when adjectives (i.e., enthusiasm/elation and energy/excitement) were examined separately (r's $\leq .17$, p's $\geq .208$).

For change in activated positive affect, a positive relationship was far from significance [$r(56) = .13$, $p = .531$], although this was somewhat closer to significance for the enthusiasm/elation component [$r(55) = .17$, $p = .213$].

For deactivated positive affect at the post-induction timepoint, there was no evidence of a relationship with EBR [$r(56) = -.02$, $p = .876$].

For change in deactivated positive affect, a weak negative correlation approached significance [$r(56) = -.24$, $p = .075$].

Therefore, this provides some tentative evidence of a weak (but non-significant) positive relationship between EBR and activated positive affect, and, in contrast, a weak (but non-significant) relationship between EBR and deactivated positive affect.

7.4.6. Relationships between EBR and AX-CPT Performance

To examine the fit for relationships between EBR and performance on the AX-CPT, separate regression analyses were conducted to examine EBR as a predictor of RTs and error rates on AY and BX trials. To avoid potentially problematic high multicollinearity with the quadratic term, these variables were centred prior to analysis (Aiken & West, 1991). For all analyses, EBR was entered in the first step to test a linear fit, and the quadratic term (EBR centred value squared) was entered in the second step.

Coefficients and probability values for all models are displayed in Table 7.1.

Table 7.1. *Coefficients and probability values for tests of linear and quadratic relationships between EBR and AX-CPT performance.*

	Linear		Quadratic	
	β	*p*	*β*	*p*
RTs				
AY	-0.01	.926	-0.77	.259
BX	0.01	.934	-0.61	.370
Error Rates				
AY	0.07	.602	-0.84	.215
BX	0.05	.709	-1.19	.079

Scatterplots displaying regression lines for RTs on AY and BX trials can be seen in Figure 7.8 and Figure 7.9, whilst regression lines for error rates can be seen in Figure 7.10 and Figure 7.11.

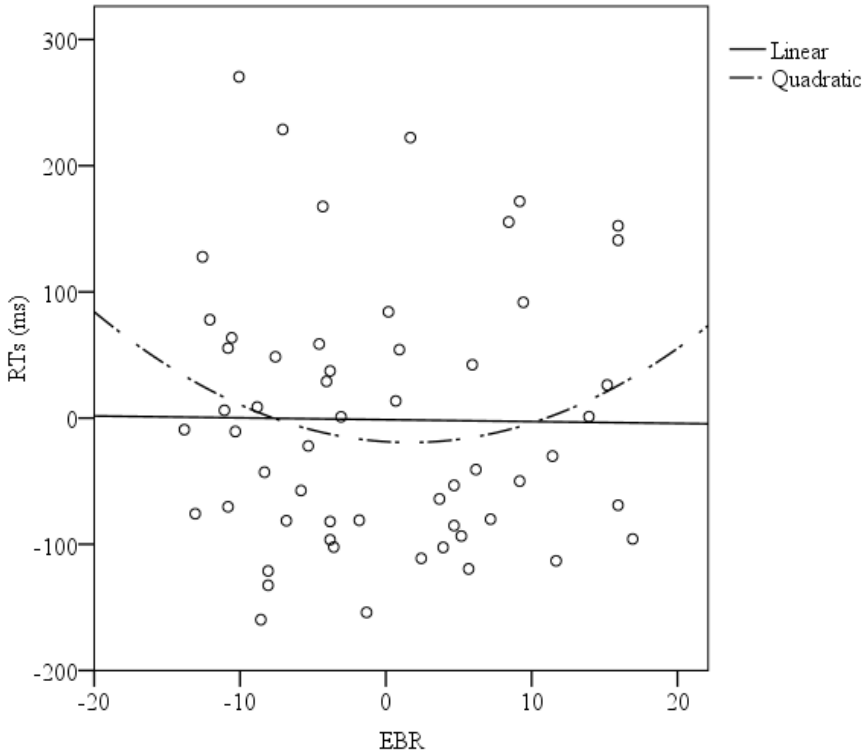


Figure 7.8. *RTs for AY trials on the AX-CPT as a function of EBR.*

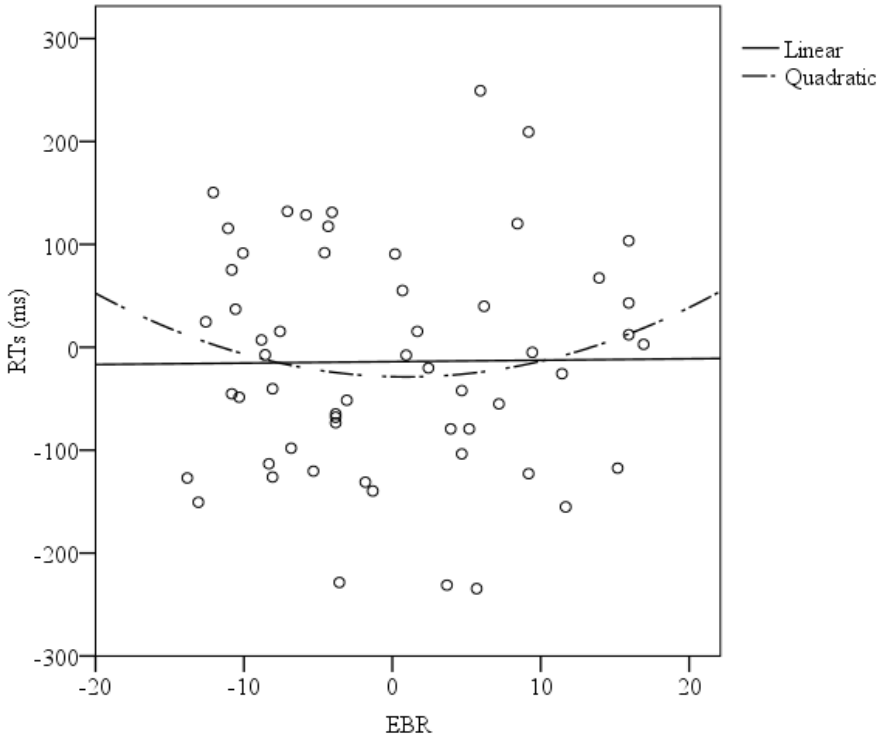


Figure 7.9. *RTs for BX trials on the AX-CPT as a function of EBR.*

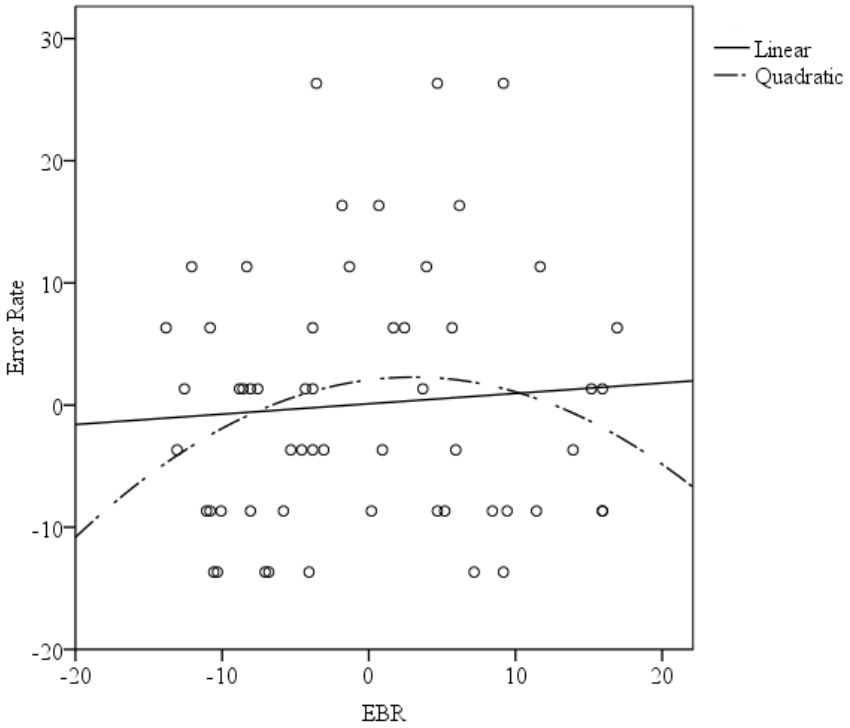


Figure 7.10. *Error rates for BX trials on the AX-CPT as a function of EBR.*

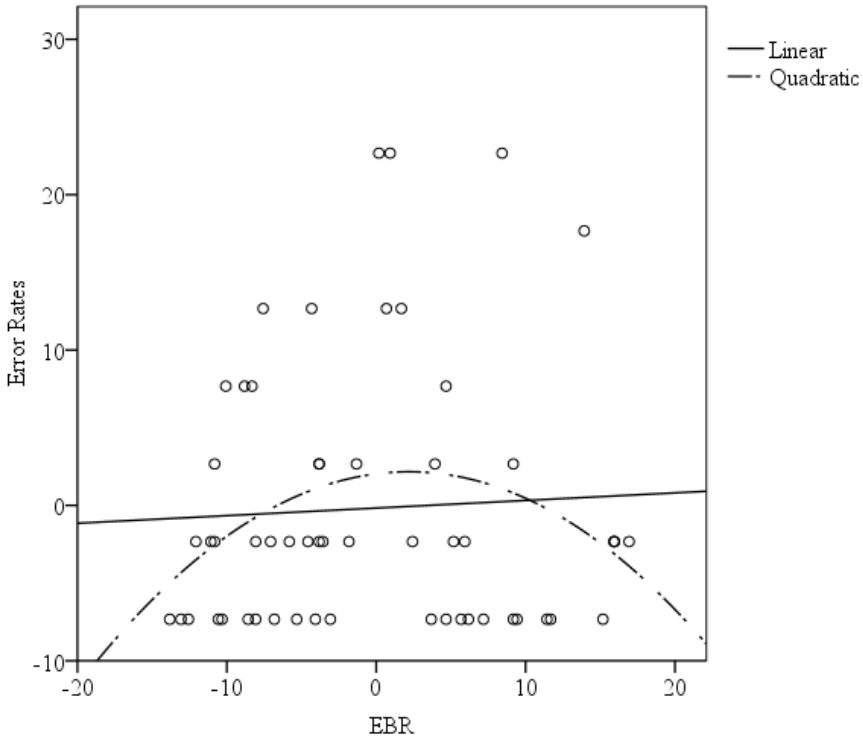


Figure 7.11. *Error rates for AY trials on the AX-CPT as a function of EBR.*

For AY RTs, the linear model was far from significance [*R2*= 0.00, *F*(1,54) = 0.01, *p* = .926], and adding the quadratic term did not significantly explain additional variance [Δ*R2* = 0.02, *F*(1,53) = 1.30, *p* = .259]. The linear model for BX RTs was also far from significance [*R2*= 0.00, *F*(1,54) = 0.01, *p* = .934], and, again, adding the quadratic term did not significantly explain additional variance [Δ*R2* = 0.02, *F*(1,53) = 0.82, *p* = .370].

For AY error rates, the linear model was far from significance [*R2*= 0.01, *F*(1,54) = 0.27, *p* = .602], and adding the quadratic term did not significantly explain additional variance [Δ*R2* = 0.03, *F*(1,53) = 1.58, *p* = .215]. This was also the case for BX error rates, as the linear model was also far from significance [*R2*= 0.00, *F*(1,54) = 0.14, *p* = .709]. However, adding the quadratic term in this model did almost reach significance, in terms of explaining additional variance [Δ*R2* = 0.06, *F*(1,53) = 3.21 *p* = .079].

Therefore, this suggests that there is little evidence of differential linear or quadratic relationships, between EBR and RTs or error rates, on AY and BX trials.

7.4.7. Moderating Effect of EBR on AX-CPT Performance

To examine whether EBR moderated performance on the AX-CPT, a median split was conducted for EBR to produce a categorical variable with two levels.

7.4.7.1. RTs

A 4 (cue-probe condition: AX/AY/BX/BY) by 2 (EBR: higher/lower) mixed ANOVA was conducted with RTs as the dependent variable. As Mauchly's test of sphericity was found to be significant for the cue-probe condition, the Greenhouse Geisser procedure was applied to correct for an inflation of Type I error (ε=.80) in this analysis.

In line with previous analysis, the main effect of cue-probe condition was significant, [*F*(2.54,137.32) = 214.99, *p* < .001, η^2p = 0.80]. The main effect for EBR was not significant, [*F*(1,54) = 0.07, *p* = .797, η^2p = 0.00]. However, the pertinent cue-probe condition by EBR interaction did also approach significance [*F*(2.54,137.32) = 2.78, *p* = .052, η^2p = 0.50].

Planned contrasts were conducted using simple effects analysis with independent t-tests to examine differences in RTs with cue-probe conditions for those with a higher and lower EBR. A Bonferroni correction was used to correct for inflated Type I error due to the four multiple comparisons (α = .013). The means for this analysis can be seen in Figure 7.12.

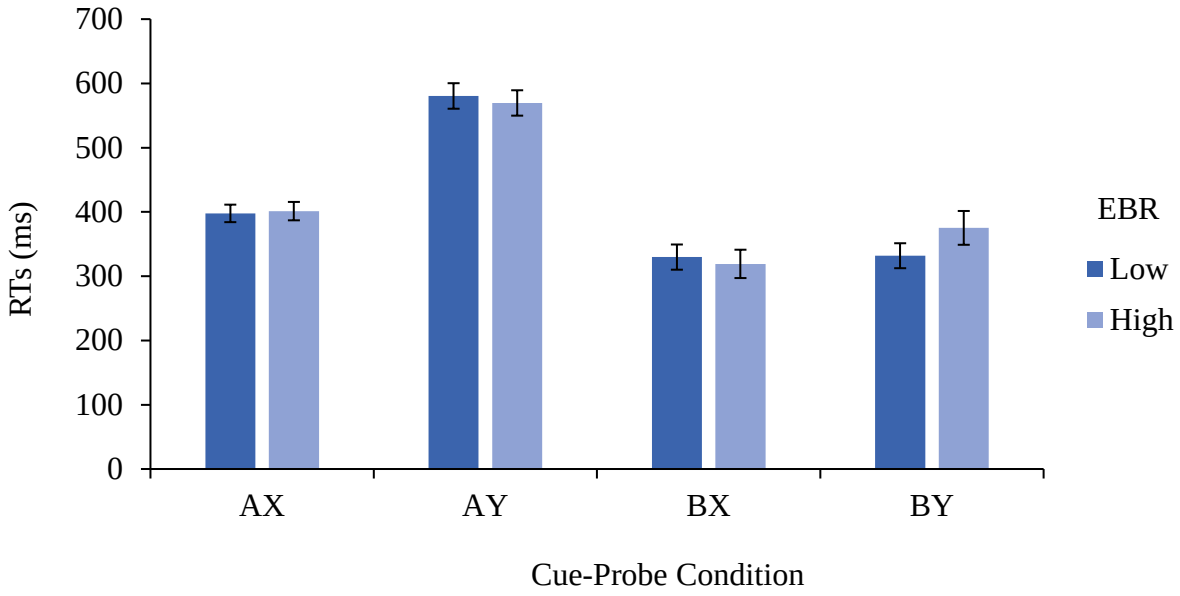


Figure 7.12. *RTs as a function of cue-probe and EBR condition. Error bars reflect one standard error above and below the mean. Bonferroni correlation due to four multiple comparisons (α = .013).*

Figure 7.12 demonstrates that there were no significant differences in RTs for those with higher compared to lower EBR in AX, AY, or BX trials (*p*'s ≥ .349). However, there was a trend towards slower RTs on BY trials for those with a lower EBR, but this was not significant [*t*(54) = -1.33, *p* = .096, *d* = -0.35].

This is in line with regression analyses examining the fit for relationships between EBR and RTs on the AX-CPT (see Table 7.1), which found no evidence of differential linear or quadratic relationships for AY and BX trials.

Therefore, this suggests that, overall, EBR did not to moderate RTs on the AX-CPT.

7.4.7.2. Error Rates

A 2 (cue-probe condition: AY/BX) by 2 (EBR: higher/lower) mixed ANOVA was also conducted with error rates as the dependent variable. Levene's test for homogeneity of variance was significant for BX trials, but this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups.

In line with previous analysis, the main effect of cue-probe condition was significant [*F*(1,54) = 15.19, *p* < .001, η^2p = 0.22]. However, the main effect for EBR also approached significance, [*F*(1,54) = 3.15, *p* = .082, η^2p = 0.06], such that error rates were greater for individuals with a higher EBR (*M* = 12.14% *SD* = 7.14) compared to lower EBR (*M* = 8.75%, *SD* = 7.14).

However, the pertinent cue-probe condition by EBR interaction was not significant [$F(11,54) = 0.10$, $p = .753$, $\eta^2p = 0.00$]. The mean error rates for those with a higher and lower EBR within cue-probe conditions can be seen in Figure 7.13.

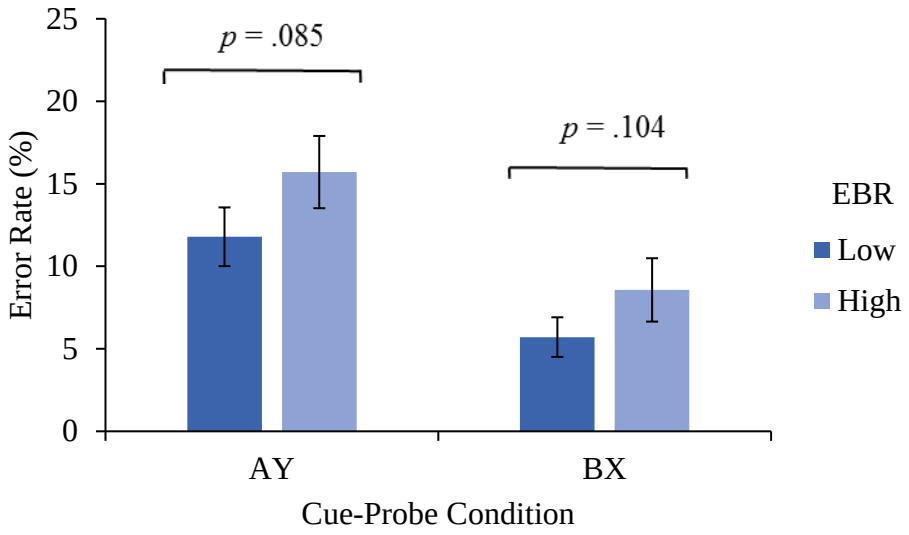


Figure 7.13. *Error rate as a function of cue-probe and EBR condition. Error bars reflect one standard error above and below the mean. Bonferroni correlation due to two multiple comparisons (α = .025).*

This is in line with regression analysis examining the fit for relationships between EBR and error rate on the AX-CPT (see Table 7.1), which found no evidence of differential linear or quadratic relationships for AY and BX trials.

Therefore, this suggests that, overall, EBR did not to moderate error rates on the AX-CPT.

7.4.8. Moderating Effect of EBR on Positive Mood and AX-CPT Performance

To examine whether EBR moderated performance on the AX-CPT, a median split was again conducted for EBR to produce a categorical variable with two levels.

7.4.8.1. RTs

To examine whether EBR moderated the effect of positive mood on the AX-CPT, a 2 (cue-probe condition: AY/BX) by 3 (mood condition: neutral/low appetitive/high appetitive) by 2 (EBR: higher/lower) mixed ANOVA was conducted with RTs as the dependent variable.

The results of this ANOVA are displayed in Table 7.2, which demonstrates that main effects for cue-probe condition and mood condition were significant. As these main effects have been reported in detail within previous analyses, they will not be repeated here. However, all

interaction effects were found to be non-significant ($p \geq .144$), which was also the case for the pertinent cue-probe by mood condition by EBR interaction.

Table 7.2. *ANOVA results for differences in RTs dependant on cue-probe, mood condition, and EBR.*

Effect	df	*F*	*p*	η^2_p
Cue-Probe Condition	1, 50	423.02	< .001	0.89
Mood Condition	2, 50	3.74	.031	0.13
EBR	1, 50	0.00	.969	0.00
Cue-Probe by Mood Condition	2, 50	2.02	.144	0.08
Cue-Probe Condition by EBR	1, 50	0.09	.764	0.00
Mood Condition by EBR	2, 50	0.33	.718	0.01
Cue-Probe by Mood Condition by EBR	2, 50	0.76	.471	0.03

Although common practice in research examining EBR, dictomising this variable by performing a median split may be problematic because it results in a loss of statistical power, which can increase the chance of Type II error (Aiken & West, 1991). Therefore, regression analysis was also conducted to examine whether EBR moderated the effect of the positive mood inductions on RTs on the AX-CPT.

Two separate models were conducted with AY and BX RTs as the dependent variables. In the first step, EBR was entered as a continuous predictor variable. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect contrasts between: i) high appetitive compared to neutral and low appetitive; and ii) low appetitive compared to neutral and high appetitive. In the second step, product terms were also entered, to reflect the interaction between EBR and the mood condition dummy variables. Continuous variables were centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

For AY RTs, the overall model effect at step one was not significant [R^2= .05, F(3,52) = .99, p = .405], although examination of individual predictors (displayed in Table 7.3) suggests a trend towards slower RTs for the high appetitive condition contrast, which is in line with ANOVA analyses (Figure 7.5).

However, no additional variance in this model was explained by adding the interaction terms for EBR and mood condition dummy codes [ΔR^2= .00, F(2,50) = .02 p = .984].

Table 7.3. *Coefficients and significance values for individual predictors in regression models for moderation of AY RTs by mood condition and EBR.*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Mood – High Appetitive	59.39	34.79	.27	1.71	.094
Mood – Low Appetitive	37.95	34.41	.18	1.10	.275
EBR	.05	1.58	.00	.03	.974
Step 2					
Mood – High Appetitive	59.23	35.54	.27	1.07	.290
Mood – Low Appetitive	37.59	35.15	.18	1.04	.307
EBR	-.40	3.32	-.04	-.12	.904
Mood – High Appetitive by EBR	.78	4.39	.05	.18	.860
Mood – Low Appetitive by EBR	.47	4.10	.03	.11	.910

For BX RTs, the overall model effect at step one was significant [R^2= .21, F(3,52) = 4.51, p = .007]. Examination of individual predictors (displayed in Table 7.4) demonstrated that both high and low appetitive condition contrasts contributed to this model, and predicted slower RTs, in line with ANOVA analyses (Figure 7.5).

However, additional variance was not explained by adding the interaction terms for EBR and mood condition dummy codes [ΔR^2= .03, F(2,50) = .95 p = .393].

Table 7.4. *Coefficients and significance values for individual predictors in regression models for moderation of BX RTs by mood condition and EBR.*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Mood – High Appetitive	123.03	24.37	.54	3.67	.001
Mood – Low Appetitive	73.22	33.57	.54	2.21	.032
EBR	.54	1.52	.04	.35	.726
Step 2					
Mood – High Appetitive	121.10	33.67	.53	3.60	.001
Mood – Low Appetitive	70.93	33.30	.31	2.13	.038
EBR	-3.20	3.15	-.26	-1.02	.314
Mood – High Appetitive by EBR	5.40	4.16	.25	1.30	.200
Mood – Low Appetitive by EBR	4.52	3.88	.25	1.17	.249

Therefore, this analysis suggests that EBR did not moderate the influence of mood on RTs within cue-probe conditions in the AX-CPT.

7.4.8.2. Error Rates

EBR was not examined as moderator the effect of positive mood on error rate on the AX-CPT, using ANOVA, as this data was no longer determined to reflect a continuous scale with sufficient variance for analysis when examined in the smaller cell sizes required for this analysis.

However, regression analysis was conducted using EBR as a continuous (rather than dictomised) variable.

Two separate models were conducted with AY and BX error rates as the dependent variables. In the first step, EBR was entered as a continuous predictor variable. Mood condition was also entered as a categorical predictor in this step, using dummy codes to reflect contrasts between: i) high appetitive compared to neutral and low appetitive; and ii) low appetitive compared to neutral and high appetitive. In the second step, product terms were also entered, to reflect the interaction between EBR and the mood condition dummy variables. Continuous variables were

centred prior to analysis to avoid potentially problematic high multicollinearity with the product term (Aiken & West, 1991).

For AY error rates, the overall model effect at step one was significant [R^2= .51, F(3,52) = 6.20, p = .001], but examination of individual predictors (displayed in Table 7.5) suggests a trend towards lower error rates for the high appetitive condition contrast, as well as the low appetitive contrast, which is in line with ANOVA analyses (Figure 7.5).

However, no additional variance in this model was explained by adding the interaction terms for EBR and mood condition dummy codes [ΔR^2= .02, F(2,50) = .81 p = .449].

Table 7.5. *Coefficients and significance values for individual predictors in regression models for moderation of AY error rates by mood condition and EBR.*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Mood – High Appetitive	-12.76	3.14	-.57	-4.07	<.001
Mood – Low Appetitive	-10.20	3.10	-.46	-3.29	.002
EBR	.04	0.14	.03	.25	.801
Step 2					
Mood – High Appetitive	-12.54	3.16	-.56	-3.97	<.001
Mood – Low Appetitive	-10.06	3.12	-.46	3.22	.002
EBR	.36	.30	.30	1.23	.226
Mood – High Appetitive by EBR	-.39	.39	-.18	-1.00	.427
Mood – Low Appetitive by EBR	-.45	.36	-.25	-1.24	.341

For BX error rates, the overall model effect at step one was not significant [R^2= .25, F(3,52) = 1.19, p = .324]. Individual predictors are displayed in Table 7.6, which demonstrates that no variables significantly predicted variance in error rates, although there was evidence that the high appetitive condition contrast (non-significantly) predicted lower error rates, in line with ANOVA analysis (Figure 7.6).

However, at step two, the model approached significance when adding the adding the interaction terms for EBR and mood condition dummy codes [ΔR^2= .10, F(2,50) = 2.93 p = .063].

Individual predictors displayed in Table 7.6 demonstrates that there was a trend towards significance for the high appetitive condition contrast, such that this predicted lower error rates. There was also a trend towards significance for the EBR and the low appetitive condition contrast interaction term. Examination of the coefficients suggests that there was a pattern towards higher error rates for those with a higher EBR in the low appetitive condition. However, it is important to note that this did not reach significance.

Table 7.6. *Coefficients and significance values for individual predictors in regression models for moderation of BX error rates by mood condition and EBR.*

Variables	*B*	*SE*	*β*	*t*	*p*
Step 1					
Mood – High Appetitive	-4.26	2.84	-.24	1.50	.140
Mood – Low Appetitive	.30	2.81	.02	.11	.916
EBR	.04	.13	.05	.34	.728
Step 2					
Mood – High Appetitive	-4.64	2.74	-.26	-1.69	.097
Mood – Low Appetitive	.43	2.71	.02	.16	.875
EBR	-.18	.26	-.19	-.70	.487
Mood – High Appetitive by EBR	-.09	.34	-.05	-.25	.804
Mood – Low Appetitive by EBR	.55	.32	.39	1.75	.086

Therefore, this analysis suggests that there is little evidence that EBR moderated the influence of mood on error rates within cue-probe conditions in the AX-CPT.

7.5. Discussion

7.5.1. Positive Mood and Stability

The present study examined the moderating role of appetitive motivation in relation to the influence of positive mood on stability in cognitive control, using the AX-CPT. It was hypothesised that positive mood low in appetitive motivation would result in reduced stability on this task, which was expected to be demonstrated by: i) slower RTs on BX trials and/or faster RTs on AY trials; and ii) lower error rates on AY trials and/or increased error rates on BX trials. This was based on the assumption that reduced stability is beneficial on AY trials

because maintenance of the A cue is associated with the incorrect response (i.e., resulting in slower RTs and more errors), whilst maintenance of the B cue is detrimental on BX trials because it is associated with the correct response (i.e., resulting in faster RTs and more errors). However, the present study found no significant differences in RTs for any trial type (i.e., AY or BX) in the low appetitive, compared to the neutral, condition. Despite this, error rates were found to be lower on AY trials, whilst no differences observed on BX trials. Therefore, results were partially in line with hypotheses.

The finding that positive affect low in appetitive motivation had no effect on RTs is not in line with previous studies (assumed to induce positive affect low in appetitive motivation), which found that presenting positive images prior to each trial resulted in faster RTs for AY trials (Dreisbach, 2006) or slower RTs on BX trials (Frober & Dreisbach, 2014). However, neither of these findings were replicated in the present study. Despite this, positive affect low in appetitive motivation was found to result in a decrease in error rate on AY trials, which is in line with hypotheses. This finding is also consistent with both of the aforementioned studies (i.e., Dreisbach, 2006; Frober & Dreisbach, 2014), which also found that error rate was reduced on AY trials. Interestingly, the results of the present study (i.e., reduced error rate on AY trials, but no effect on RTs) mirror those observed in another study, conducted by van Wouwe et al. (2011), which is the only other study to date that has examined the influence of a more enduring positive mood state (i.e., participants watched positive film clips prior to task completion) on AX-CPT performance.

The finding that positive mood low in appetitive motivation had no effect on RTs is not in line with the suggestion that this should reduce stability in cognitive control. One explanation for this null result may be that more enduring mood states, such as those induced in the present study (and the study conducted by van Wouwe et al., 2011), may have weaker effects on cognitive control processes. This is in comparison to the more transient, yet more temporally aligned, emotional responses induced by the brief presentation of positive images prior to each trial (i.e., Dreisbach, 2006; Frober & Dreisbach, 2014). A similar suggestion was made to explain findings observed in Study 4, which examined the influence of positive mood on a set-shifting paradigm. Previous studies had demonstrated greater flexibility (i.e., reduced stability) on this paradigm when positive affect (specifically that low in appetitive motivation) was induced using the brief presentation of positive images (e.g., Liu & Wang, 2014). Study 4 demonstrated that a more enduring positive mood state produced a similar pattern of results,

but that these effects were much weaker, compared to those observed in previous studies inducing transient emotional responses.

Whilst positive mood low in appetitive motivation was hypothesised to result in reduced stability in cognitive control, positive mood high in appetitive motivation was hypothesised to result in greater stability in cognitive control. This was expected to be demonstrated by: i) faster RTs across all cue-probe conditions (i.e., AX, AY, BX, and BY trials); and ii) increased error rates on AY trials. This was based on the proposition that enhanced maintenance of contextual cue information facilitates task preparation, which allows faster responses across all trial types, but that this is also detrimental only for AY trials as maintenance of the A cue is associated with the incorrect response (i.e., resulting in more errors). However, error rate should be unaffected on BX trials, as enhanced maintenance of the B cue is associated with the correct response. However, RTs were found to be slower on all cue-probe conditions, and error rates were found to be decreased on both AY and BX trials, in the high appetitive (compared to the neutral) condition. Therefore, this is not in line with hypotheses, and does not provide any evidence that positive mood high in appetitive motivation results in greater stability in cognitive control.

7.5.1.1. Speed-Accuracy Trade-Off

The finding of slower RTs and a decrease in error rate for all trial types in the high appetitive condition suggests that participants may have been prioritising accuracy over speed when responding. This assumes that AX-CPT performance requires a trade-off between the speed and accuracy of responses, which suggests that faster responses occur at the cost of reduced accuracy, whilst more accurate responses occur at the cost of reduced speed (Heitz, 2014). The setting of this trade-off is suggested to be determined by a "response threshold", such that accuracy is prioritised over speed when this threshold is higher, whilst speed is prioritised over accuracy when this threshold is lower (Kunde, Reuss, & Kiesel, 2012). Therefore, individuals in the high appetitive condition of the present study may have set a higher response threshold (resulting in the prioritisation of accuracy over speed), possibly reflecting a more focused and cautious response style. However, it is unclear whether a higher response threshold in this condition reflects pre-existing individual differences or an effect of the positive mood induction that was high in appetitive motivation.

The present study used a between-subjects design (without a baseline AX-CPT assessment), which did not allow pre-existing or individual differences, which may have influenced task

performance (e.g., response threshold), to be considered. Therefore, future studies examining performance on the AX-CPT should ensure that the study design allows for these factors to be assessed. For example, a within-subjects design could have been used in the present study, which would have allowed performance to be compared in neutral and positive mood inductions completed within the same group of participants. However, this introduces the limitations of practice effects (i.e., participants are completing the AX-CPT multiple times) and order effects (i.e., counterbalancing of the order participants complete the mood inductions is required). Alternatively, a between-subjects design could have been used for completion of the mood inductions, with the inclusion of a baseline assessment (i.e., the AX-CPT could be compared within-subjects at pre- and post-mood inductions). This is similar to the design used in Study 4, and overcomes problems with practice and order effects.

The suggestion that the mood induction in the high appetitive condition may have resulted in an increase in the response threshold of participants is supported by examination of the relationships between RTs and self-reported affect following the mood inductions. Whilst there were no relationships between deactivated positive affect and RTs for any of the cue-probe conditions, a positive relationship was found for RTs on AY trials and change in activated positive affect. Alone, this observation may be suggested to reflect greater stability in cognitive control (i.e., slower RTs due to enhanced active maintenance of the cue associated with an incorrect response), but similar relationships were also observed to occur for RTs and change in activated positive affect for all the other cue-probe conditions. Therefore, this corroborates the general slowing of RTs that was observed to occur across all trial types in the high appetitive condition. Specifically, this suggests that the increased prioritisation of accuracy (over speed) in responding was related to the specific affective characteristics (i.e., greater activated positive affect), associated with a positive mood state that is high in appetitive motivation.

Previous studies examining the effect of performance-based rewards on the AX-CPT have found faster RTs across all trial types and an increase in error rate specifically on AY trials (Chiew & Braver, 2013, 2014; Frober & Dreisbach, 2014; Locke & Braver, 2008). These results are not suggested to reflect a general speed-accuracy trade-off (i.e., prioritisation of speed at the cost of accuracy), but instead reflect greater stability in cognitive control, as error rate is reduced significantly on AY trials only (i.e., the only trial type for which greater stability may be detrimental for performance). However, the findings of the present study do not replicate these results, which suggests that positive affect high in appetitive motivation does

not have the same effect on the AX-CPT as performance-based reward incentives. This is in line with the reward-as-motivation hypothesis (Goschke & Bolte, 2014), in terms of suggesting that an individual must be actively engaged in the pursuit of a reward related to the current task performance (cf., experience of positive affect that is unrelated to the task) for stability in cognitive control to be increased.

7.5.1.2. Motivational intensity Model vs. Reward-as-Motivation Hypothesis

The reward-as-motivation hypothesis also suggests that positive affect that is unrelated to task performance results in greater flexibility in cognitive control (Goschke & Bolte, 2014). However, the motivational intensity model (Gable & Harmon-Jones, 2010) suggests that the effect of positive affect on cognition is dependent on the motivational intensity of positive affect. This is such that positive affect low in appetitive motivation results in broader and more flexible cognition, whilst narrower and more stable cognition occurs for positive affect that is high in appetitive motivation. The present study does provide some support for the broad claims of the motivational intensity model (i.e., positive mood high and low in appetitive motivation were found to have differential effects on the AX-CPT). However, the findings are not in line with the specific directional predictions of this model, as, although positive mood low in appetitive motivation may have resulted in reduced stability in cognitive control (i.e., reduced error rate only on AY trials), positive mood high in appetitive motivation was not found to result in greater stability (i.e., as a general increase in RTs and error rates was observed across all trial types).

The effects of reward incentives on AX-CPT performance are suggested to be dependent on timing, such that incentives must occur in close temporal proximity to the presentation of cues, allowing the enhanced maintenance of this information (Chiew & Braver, 2016). Therefore, it may be the case that the effects of more enduring mood states that are high in appetitive motivation do not facilitate stability in cognitive control on the AX-CPT, as this does not coincide with the presentation of the cues. This mechanism may also provide a partial account for Liu and Wang's (2014) finding that the influence of positive affect on Dreisbach and Goschke's (2004) set-shifting paradigm was moderated by motivational intensity. Within this study, positive affect positive affect high in appetitive motivation was found to result in reduced flexibility (i.e., greater stability). However, as positive affect was induced using briefly presented images prior to each trial on the set-shifting paradigm, this may have mimicked the

effect of performance-dependent reward incentives, due to the close temporal proximity of positive affect high in appetitive motivation and demands of the task.

Study 4 demonstrated that Liu and Wang's (2014) findings were not replicated when using a positive mood induction high in appetitive motivation. This is in line with the suggestion that, in order to increase cognitive stability (or, conversely, reduce flexibility), manipulations of positive affect high in appetitive motivation must occur within close temporal proximity to task demands. Interestingly, while the mood induction method failed to replicate Liu and Wang's (2014) findings, positive mood high in appetitive motivation was found have a detrimental effect across switch conditions, possible reflecting more effortful control and an increase in cognitive stability. It was suggested that working memory load may be increased due to the enhanced maintenance of representations associated with content of the mood inductions (i.e., that are task-irrelevant). This may have had a detrimental effect on performance due to reduced capacity when cognitive control demands were increased on post-switch trials. Therefore, an increased response threshold in the present study may reflect a strategy adopted to overcome the detrimental effect of an increased working memory load on AX-CPT performance.

Only one other study has examined the differential influence of positive mood states that can be described as being high and low in appetitive motivation on the AX-CPT. This study was conducted by Wacker (2017) and provided some evidence that RTs were slower on AY trials and faster on BX trials for the high compared to low appetitive mood inductions, which is in line with greater stability in cognitive control. However, these results are difficult to interpret without the inclusion of a neutral or baseline comparison, and error rates were also not analysed due to limited variance (i.e., most participants made zero errors). Furthermore, the mood inductions did not result in the expected changes to positive affect, so it is unclear whether these induced appropriate mood states. Therefore, future research needs to be conducted to ascertain whether findings of the present study can be replicated using a within-subject design or baseline assessment of AX-CPT performance. This will rule out the possibility that pre-existing individual differences, such as in response threshold, may underlie the results observed in the high appetitive condition.

It would also be interesting to examine whether the effects of performance-based reward incentives on the AX-CPT can be replicated with the presentation of appetitive images. As outlined above, it may be the case that more enduring positive mood states high in appetitive motivation do not result in greater stability in cognitive control, as these are not occurring in close temporal proximity to the contextual information related to task performance. As Liu and

Wang (2014) have demonstrated that more transient emotional responses can result in reduced flexibility (i.e., greater stability) on a set-shifting paradigm, it may be the case that the same effect occurs on the AX-CPT. Therefore, performance on this paradigm could be examined when images that vary in motivational intensity are presented prior to each trial (i.e., blocks for which images are neutral, low in appetitive motivation, and high in appetitive motivation could be compared). It would be interesting to ascertain whether effects occur for these images, as they do not involve the active involvement in reward pursuit that is emphasised in the reward-as-motivation hypothesis (Goschke & Bolte, 2014).

7.5.2. Neurobiological Mechanisms

7.5.2.1. Positive Mood and EBR

The present study also examined the neurobiological mechanisms underlying the possible influence of positive mood states that were high and low in appetitive motivation on stability in cognitive control. This was assessed using an indirect physiological measure of dopamine activity (i.e., EBR). Based on the results of Studies 2 and 4 of the current research, it was hypothesised that EBR would be greater than for only the positive mood induction that was high in appetitive motivation (i.e., compared to the neutral induction). However, no differences in EBR were found between the neutral condition and either the high or low appetitive mood induction groups. Although this suggests that neither of these mood inductions affected dopamine activity, this could have been due to the use of a between-subjects design, which did not include a baseline assessment of EBR. Consequently, pre-existing individual differences in EBR were not assessed, and this may have masked potential effects of the mood inductions. This is supported by the finding that these mood inductions had significant effects in Studies 2 and 4, which both used within-subjects designs and compared EBR during neutral and positive inductions within the same participants.

It is also important to note that the mood induction high in appetitive motivation did not result in the significant increases in activated positive affect that were expected to be observed in this condition, which may have also contributed to the null results for the influence of this mood induction on EBR. Despite this, there was some evidence of a non-significant and weak positive trend between EBR and self-reported activated positive affect across mood conditions, whilst there was evidence of a weak negative trend between EBR and deactivated positive affect. An increase in activated positive affect is suggested to occur during positive mood high

in appetitive motivation (whilst an increase in deactivated positive affect is suggested to occur during positive mood low in appetitive motivation) (Depue & Collins, 1999). Based on this (and the finding that the effect of the positive mood induction high in appetitive motivation on activated positive affect was close to significance), it may seem likely that the most important factor in producing null results for the effect of mood conditions on EBR was the use of a between-subjects design, as this did not take into account any pre-existing differences in EBR.

7.5.2.2. EBR and Stability

The relationships between EBR and performance on the AX-CPT were examined. It was hypothesised that there would be a negative (or possibly U-shaped) relationship between EBR and RTs/error rates on AY trials, whilst there would be a positive (or inverted U-shaped) relationship between EBR and RTs/error rates on BX trials. However, there was little evidence of any reliable linear or non-linear relationships, especially for RTs on both cue-probe conditions. In addition to the lack of significant correlations with RTs, the relationships observed were also found to be in the same direction (i.e., negative or U-shaped) for both AY and BX trials. As stability in cognitive control is suggested to be reflected on the AX-CPT by opposite effects on these cue-probe conditions, this does not support a clear relationship between EBR and indices of cognitive stability on this task. Despite this, there was a trend towards an inverted U-shaped relationship between EBR and error rate on BX trials. Although this was in line with hypotheses, a similar trend was also observed for the relationship between EBR and error rate on AY trials. Therefore, this, again, does not support the suggestion of a relationship between EBR and stability in cognitive control.

It was also hypothesised that EBR would moderate performance on the AX-CPT, such that those with a higher (compared to lower) EBR would have a decrease in RTs/error rates on AY trials, but an increase in RTs and/or error rates on BX trials, reflecting greater stability in cognitive control. However, in line with the lack of relationships between EBR and RTs, EBR was also not found to moderate performance on the AX-CPT. However, there was a trend towards a greater error rate for those with a higher (compared to lower EBR), but this was for both AY and BX trials. Therefore, this reflects the trend towards inverted U-shaped relationships outlined above, and does not provide any evidence for a relationship between EBR (i.e., assumed to reflect dopamine activity in the prefrontal cortex) and stability in cognitive control. In addition, the moderating effect of EBR was also explored in relation to the influence of positive mood on the AX-CPT. There was not enough variance in the data for

error rates when these were examined in these smaller cell sizes, so these were not included in analysis. However, no moderating effects were found for EBR in relation to the influence of positive mood on RTs on this paradigm.

7.5.3. Conclusions

The present study examined the moderating role of appetitive motivation in relation to the influence of positive mood on stability in cognitive control, using the AX-CPT. It was hypothesised that positive mood low in appetitive motivation would result in decreased stability (RTs slower on BX trials and/or faster on AY trials, but error rates lower on AY trials and/or higher on BX trials). Whilst no difference in RTs were found between trial types, error rates were lower only on AY trials, which is in line with hypotheses. This mirrors the findings of van Wouwe et al. (2011), who also examined the influence of an enduring positive mood state (presumably low in appetitive motivation) on AX-CPT performance. However, previous studies that have induced transient emotional responses (also presumed to be low in appetitive motivation) have demonstrated effects on RTs, as well as error rate (e.g., Frober & Dreisbach, 2014). Therefore, this suggests that the effects of more enduring mood states may be weaker on cognitive control processes compared to more transient emotional responses.

In contrast, positive mood high in appetitive motivation was hypothesised to result in greater stability in cognitive control (i.e., faster RTs across all trial types, or at least AY trials, and/or decreased error rate only on BX trials). This was in line with previous studies examining the effects of performance-based reward incentives on AX-CPT performance (e.g., Frober & Dreisbach, 2014). However, RTs were found to be slower, and error rate was found to be greater, across all trial types, which was not in line with hypotheses. This suggests the prioritisation of accuracy over speed of responses in this condition, possibly reflecting a higher response threshold, and a more focused and cautious response style. This may be due to pre-existing individual differences for participants in this condition, as a between-subject design without a baseline comparison was used to assess the effect of mood inductions on AX-CPT performance. However, there was some evidence of a positive relationship between changes in activated positive affect and RTs across trial types, which suggests that this effect may be due to the induction of positive mood high in appetitive motivation.

Although divergent effects for the positive mood inductions on AX-CPT performance is in line with the motivational intensity model (Gable & Harmon-Jones, 2010), the effects observed for positive mood high in appetitive motivation were not in line with the specific directional

predictions of this model. Therefore, findings may be more in line with the reward-as-motivation hypothesis, which suggests that the active pursuit of reward is required for greater stability in cognitive control to occur. It was suggested that positive affect high in appetitive motivation may result in enhanced maintenance of task-relevant contextual information only when it occurs in close temporal proximity to stimulus presentation/response, such that it mimics the effect of performance-dependent rewards. It was suggested that enhanced maintenance of task-irrelevant information may occur as a result of more enduring mood inductions that occur at a temporal distance from task demands and may be detrimental to performance. It was speculated that this may result in a higher working memory load, leading to reduced resources in the higher appetitive condition. Therefore, this may have resulted in the adoption of a higher response threshold to counteract this effect.

Finally, the present study also considered potential neurobiological mechanisms underlying the influence of positive mood on the AX-CPT, specifically in relation to dopamine activity. This was assessed using EBR, which was assumed to reflect activity in the prefrontal cortex, and was hypothesised to be greater only for the high appetitive condition. However, no differences in EBR were found between conditions, which may reflect the fact that the high appetitive mood induction was not found to be as effective compared to previous studies conducted as part of the current research. While there was some evidence suggesting a positive relationship between activated positive affect and EBR, it seems most likely that this lack of general EBR effect on AX-CPT performance may be due to the use of a between-subjects design, and pre-existing differences possibly masking any effects of the mood inductions. It was also hypothesised that EBR would be differentially related to RTs and error rates in AY compared to be BX trials, and that the effect of mood inductions on AX-CPT performance may be moderated by EBR. However, there was no evidence of a differential relationship between EBR and trial types, or a moderating effect of EBR on AX-CPT performance.

8. Study 6 – The effect of positive mood on EEG frontal asymmetry: The moderating role of appetitive motivation

8.1. Abstract

There is evidence that positive mood may result in greater activity in the left vs. right frontal areas - 'left frontal asymmetry' (e.g., N. A. Jones & Fox, 1992). This has been most consistently demonstrated for positive affect high in appetitive motivation (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). However, previous studies have only examined this effect in relation to transient emotional responses (i.e., briefly presented images), and have not compared this to the influence of low appetitive positive affect. Therefore, the present study examined the influence of more enduring positive mood states high and low in appetitive motivation on left frontal asymmetry. The relationship between changes in EBR and changes in left frontal asymmetry were also examined, as greater left frontal asymmetry at rest has been found to be related to greater dopamine activity (Wacker et al., 2013). However, it is unclear if this activity may underlie the effects of positive mood on left frontal asymmetry.

This study was conducted as part of the same experiment as Study 4. Forty-four participants took part, and completed a neutral and positive (either high or low appetitive) mood induction in separate sessions, using the same stimuli as Studies 1-5. The 12-PACS (Yik et al., 2011) was used to measure positive affect at pre- and post-induction timepoints. EEG was recorded during the induction period and left frontal asymmetry was calculated as alpha (8-13Hz) power from the left subtracted from the right hemisphere (F8-F7 and F4-F3). Higher values reflected greater left frontal asymmetry, and indexes were averaged to provide a composite left frontal asymmetry index. EBR was determined from EEG recordings.

ANOVAs demonstrated that left frontal asymmetry was only increased for the high appetitive induction. Therefore, this is the first study to demonstrate this effect for a more enduring mood state, and using a low appetitive comparison. There was a positive correlation between changes in EBR and changes in left frontal asymmetry, but this was non-significant, which may be due to low statistical power. Despite this, EBR was found to increase only for the high appetitive induction (assessed as part of Study 4). Therefore, an increase in EBR coincided with an increase in left frontal asymmetry, suggesting that greater left frontal asymmetry as a result of positive mood high in appetitive motivation may be due to increased dopamine activity.

8.2. Introduction

8.2.1. Neuropsychological Theory of Positive Affect

Findings that positive mood results in broader and more flexible cognition, such as enhanced divergent thinking (e.g., R. Friedman et al., 2007), were first suggested to be related to dopamine activity in the neuropsychological theory of positive affect (Ashby et al., 1999). This theory proposed that these effects were due to increases in the activity of the mesocorticolimbic and nigrostriatal dopamine pathways. Specifically, increased dopamine levels in the nucleus accumbens and the prefrontal cortex (i.e., mesocorticolimbic pathway) were proposed to underlie the experience of positive affect and the "selection of appropriate cognitive sets" (respectively), whilst increased dopamine levels in the basal ganglia (i.e., nigrostriatal pathway) were proposed to facilitate the ability to switch between these cognitive sets (Ashby et al., 2002). Therefore, an increase in dopamine activity along these pathways was suggested to enable less frequently activated sets to become selected, and, ultimately, to result in broader and more flexible cognition.

Neurobiological models have proposed prominent roles for both the prefrontal cortex and basal ganglia in mediating the balance between flexibility and stability in relation to cognitive control processes. Durstewitz and Seamans (2008) suggested that the tonic state of the prefrontal cortex is dominated by D1 receptor activity, facilitating the stabilisation of goal-relevant representations. This was argued to be antagonistic to the function of D2 receptors, which are suggested to be activated by phasic bursts of dopamine, enabling flexible switching between these representations. Frank and O'Reilly (2006) have proposed a similar model of the basal ganglia, in which, it was suggested that increases in dopamine activity facilitates information entry into working memory. Specifically, it was argued that the tonic state of the basal ganglia is dominated by D2 receptor activity, which suppresses information entry. However, phasic bursts of dopamine were suggested to inhibit this activity, and stimulate D1 activity, enabling updating of representations.

Frank and O'Reilly's (2006) model of the role of the basal ganglia in cognitive control is in line with the neuropsychological theory's (Ashby et al., 1999) suggestion that positive mood results in broader and more flexible cognition due to increased dopamine activity in the mesocorticolimbic pathway. However, this theory also suggests that part of the effect of positive mood on cognition is mediated by the prefrontal cortex, such that an increase in dopamine activity in the mesocorticolimbic pathway facilitates the "selection of cognitive

sets". Therefore, this is not in line with Durstewitz and Seamans' (2008) model of prefrontal dopamine activity, which suggests that an increase in this activity stimulates D1 receptor neurons, facilitating the stabilisation of working memory representations. Based on this model, it may seem more likely that positive mood results in a decrease in this tonic D1 activity and/or an increase in phasic D2 activity, which may increase the likelihood of flexible switching between representations.

8.2.2. Motivational Intensity Model

The motivational intensity model of positive affect (Gable & Harmon-Jones, 2010) suggests that the influence of positive affect on cognition depends on motivational intensity. Broader and more flexible cognition is proposed to occur for positive affect low in appetitive motivation, whilst positive affect high in appetitive motivation is proposed to result in cognition that is narrower and more stable. This is in line with the suggestion that positive affect high in appetitive motivation is associated with mesocorticolimbic dopamine activity (Depue & Collins, 1999), with dopamine projection to the prefrontal cortex being proposed to facilitate the stabilisation of representations in working memory (Smillie & Wacker, 2014). Based on this, it may be suggested that positive affect that is high in appetitive motivation may increase tonic D1 activity and/or reduce phasic D2 activity in the prefrontal cortex, in line with Durstewitz and Seamans' (2008) model of cognitive control.

In contrast, other non-dopaminergic neural substrates have been associated with positive affect low in appetitive motivation (Depue & Collins, 1999). However, there is also some evidence that positive affect is related to nigrostriatal dopamine activity. For example, Parkinson's disease (related to attenuated dopamine activity in the basal ganglia) is associated with a depressed mood (Cummings, 1992), which is also the case for patients with lesions in the basal ganglia following stroke (Vataja et al., 2004). In addition, a neuroimaging study has found that activity in this area is increased during a "happy" mood induction (Mitterschiffthaler, Fu, Dalton, Andrew, & Williams, 2007). Therefore, positive affect low in appetitive motivation may be suggested to result in broader and more flexible cognition by increasing dopamine levels in the basal ganglia, specifically in terms of increasing phasic D1 activity, activating a "Go Pathway", and/or tonic D2 activity, suppressing a "NoGo Pathway" (Frank & O'Reilly, 2006).

Based on the suggestion that positive affective states that differ in motivational intensity may differentially relate to dopamine activity, previous studies in this thesis have examined EBR

(as a physiological marker of dopamine activity) following positive mood inductions that were either high or low in appetitive motivation. Despite some null findings (i.e., Studies 1 and 5), EBR was found to be greater following the positive mood induction that was high in appetitive motivation in two separate studies (Studies 2 and 4[3]). In addition, EBR was found to be reduced following the positive mood induction that was low in appetitive motivation in Study 2, although this was not replicated in Study 4. Furthermore, it is likely that null results may be explained by the findings that mood inductions did not result in the expected changes to positive affect in Study 1, and the use of a between-subjects in Study 5, as individual differences in EBR at baseline could have masked effects of the positive mood inductions.

The findings of an increase in EBR during the high appetitive mood inductions in Study 2 and 4 were suggested to reflect an increase in prefrontal dopamine activity (greater tonic D1 dopamine activity vs. phasic D2 activity) (Durstewitz & Seamans, 2008). Therefore, this is in line with the suggestion from the motivational intensity model (Gable & Harmon-Jones, 2010) that positive affect high in appetitive motivation results in narrower and more stable cognition. The findings of a decrease in EBR for the low appetitive mood induction in Study 2 is also in line with the suggestion of a reciprocal relationship between dopamine activity in the prefrontal cortex and basal ganglia (Cools & D'Esposito, 2011). Specifically, an increase in dopamine in the basal ganglia (Frank & O'Reilly, 2006) may moderate dopamine activity in the prefrontal cortex (i.e., resulting in a decrease in EBR). Therefore, this may result in broader and more flexible cognition, as is suggested to occur as a result of positive mood that is low in appetitive motivation.

8.2.3. Appetitive Motivation and Left Frontal Asymmetry

Interestingly, it has been suggested that positive affect high in appetitive motivation may be lateralised specifically to the left hemisphere of the cortex. This was based on early clinical descriptions noting that patients with unilateral cortical lesions in the right hemisphere displayed more manic behaviours, including inappropriate indifference to injury and the

[3] It should be noted that the results presented in Study 4 were collected in the same experiment as the data in the current study. The results in the present study are presented separately to allow focus on the effect of positive mood on left frontal asymmetry and the association between EBR and left frontal asymmetry, whilst Study 4 focused on the effect of positive mood on EBR and set-shifting and the association between EBR and set-shifting. The association between left frontal asymmetry and switch costs in the set-shifting paradigm were examined, but there were no significant results. Therefore, this analysis is omitted from the present study.

experience of euphoria (Babinski, 1914). Empirical studies supported these observations, finding that patients with right hemispheric damage were more likely to minimise their symptoms, engage in laughing and joking, and to experience feelings of elation and social disinhibition (Gainotti, 1969; Hecaen, 1962). Furthermore, these responses were found to be more likely in those patients with lesions in the frontal lobes (Lipsey, Robinson, Pearlson, Rao, & Price, 1983; R. G. Robinson, Kubos, Starr, Rao, & Price, 1983; R. G. Robinson & Szetela, 1981), which led to the suggestion of "frontal asymmetries" in affective responses (Silberman & Weingartner, 1986).

Later studies examined frontal asymmetries in relation to affective responses in samples of healthy populations. EEG methodologies were used to examine neural activity in frontal areas assessed in the alpha band (i.e., neural oscillations with a frequency of 8-13Hz). Alpha activity supposedly reflects the inhibition of cortical function, so that lower alpha power is suggested to reflect greater activity in the area of the electrode site (Palva & Palva, 2007). To provide an index of left frontal asymmetry, alpha power at left electrode sites was subtracted from the corresponding right electrode sites, so that higher scores indicated greater left frontal asymmetry (i.e., more activity in the left vs. right hemisphere of the cortex). Using this method, positive correlations have been demonstrated between left frontal asymmetry at rest and the subsequent experience of positive, but not negative, self-reported affect, following affective film clips (Tomarken, Davidson, & Henriques, 1990; Tomarken, Davidson, Wheeler, & Doss, 1992; Wheeler, Davidson, & Tomarken, 1993).

Studies using state manipulations have also found that left frontal asymmetry is reduced during positive mood inductions that involved watching positive film clips compared to neutral and negative clips (N. A. Jones & Fox, 1992; Reeves et al., 1989). However, these results have not always been replicated successfully, with some studies finding null (e.g., Collet & Duclaux, 1987; Meyers & Smith, 1986), or unreliable results (Hagemann et al., 1998). It has been suggested that the failure to find consistent results may partially reflect the use of divergent mood induction methods that differentially induce appetitive motivation (Harmon-Jones et al., 2010). Specifically, findings from studies are consistent with earlier work when appetitive properties were evident in mood inductions (Davidson & Fox, 1982; Fox & Davidson, 1987; Reeves et al., 1989), but inconsistent when mood inductions were more ambiguous in motivational intensity (Collet & Duclaux, 1987; Meyers & Smith, 1986).

The suggestion that more reliable findings may occur for studies using appetitive stimuli in mood inductions is compatible with Davidson's (1992) suggestion that left frontal asymmetry

reflects lateralisation of an appetitive motivation system. This system is proposed to elicit positive affect that is high in appetitive motivation, which is associated with "anticipation", "wanting", and feelings of excitement, euphoria, elation, and enthusiasm (Depue & Collins, 1999). This is argued to be distinct from positive affect that is low in appetitive motivation, which is associated with "consummation", "liking", and feelings of contentment and satisfaction. Therefore, it may be the case that only mood inductions eliciting positive affect that is high in appetitive motivation (or has a sufficient appetitive component) results in an increase in left frontal asymmetry. This is supported by findings that indices of left frontal asymmetry are increased following the presentation of briefly presented appetitive images of desserts (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009).

Left frontal asymmetry has been suggested to reflect lateralised activity of the mesocorticolimbic dopamine system. This is supported by findings from a genetic study examining the Val158Met polymorphism of the COMT gene, which demonstrated that carriers of the Val allele (associated with lower prefrontal dopamine) had reduced left frontal asymmetry compared to carriers of the Met allele (associated with greater prefrontal dopamine) (Wacker et al., 2013). Other studies have also found that a greater willingness to expend effort to receive monetary gains on a behavioural reward task was related to greater dopamine receptor sensitivity following administration of a dopamine agonist (Treadway et al., 2012), as well as greater left frontal asymmetry assessed at rest (Hughes et al., 2015). This is further supported by findings that greater dopamine receptor density in the left prefrontal cortex at rest predicts enhanced learning following rewards (Tomer et al., 2014).

8.2.4. Present Study

Based on the literature outlined above, positive affect low in appetitive motivation may be suggested to result in an increase in dopamine activity in the basal ganglia (Mitterschiffthaler et al., 2007), whilst positive affect high in appetitive motivation may result in an increase in dopamine activity in the prefrontal cortex (Depue & Collins, 1999). An increase in prefrontal activity for positive mood high in appetitive motivation has been suggested to be lateralised to left frontal areas (Davidson, 1992). Although early studies did not consistently find that positive mood resulted in an increase in left frontal asymmetry, this has been suggested to be due to the use of inductions that were ambiguous in motivational intensity (Harmon-Jones et al., 2010). This is supported by the findings from more recent studies, which have taken motivational intensity into account, and have demonstrated that left frontal asymmetry is

increased as a result of positive affect that is high in appetitive motivation (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009).

However, manipulations used in these studies demonstrating an increase in left frontal asymmetry following the presentation of appetitive stimuli (e.g., Gable & Harmon-Jones, 2008a) likely elicit only transient emotional responses that are high in appetitive motivation. Therefore, it is unclear whether these findings can be extended to the more enduring mood states that were induced in earlier studies that produced inconsistent results. Furthermore, studies using appetitive stimuli have not provided any evidence of changes in affective state, and offered no comparison to the effect of positive affect low in appetitive motivation on left frontal alpha asymmetry. Only one previous study to date has examined left frontal asymmetry for positive mood inductions that may be described as high and low in appetitive motivation (Wacker, 2017). However, no effects were found in this study, which was likely due to a failure to effectively induce the affective properties associated with these positive mood states, as the expected changes in affect were not observed in this study.

Left frontal asymmetry at rest has been related to genetic individual differences related to dopamine activity in the prefrontal cortex (Wacker et al., 2013), as well as performance on behavioural measures that assess appetitive motivation (Treadway et al., 2012). However, there is no evidence that greater dopamine activity underlies the observed increases in left frontal asymmetry for positive affect that is high in appetitive motivation. This is despite the suggestion that the mesocorticolimbic dopamine system is involved specifically in positive affect that is high (but not low) in appetitive motivation (Depue & Collins, 1999). Furthermore, Studies 2 and 4 of the current research supported this suggestion by finding increases in EBR only for positive mood that was high (but not low) in appetitive motivation. Therefore, this may reflect greater prefrontal dopamine activity for this mood induction, in line with previous findings demonstrating that pharmacological manipulations increasing this activity have resulted in an elevated EBR (Elsworth et al., 1991).

Therefore, the present study aims to examine the effect of positive mood states that are high and low in appetitive motivation on left frontal asymmetry. To address this, left frontal asymmetry will be assessed whilst participants complete a positive mood induction (either high or low in appetitive motivation) and this will be compared to left frontal asymmetry assessed during a neutral mood induction. In line with previous findings from studies using briefly presented appetitive stimuli (i.e., Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009), it is hypothesised that only positive mood that is high in appetitive motivation will result

in an increase in left frontal asymmetry. The effect of positive mood that is low in appetitive motivation is unclear at present, so specific hypothesises are not presented. However, it would seem most likely that this will result in either no difference in asymmetry (i.e., compared to neutral mood), or possibly a decrease – due to suggestions of a reciprocal relationship between dopamine activity in the basal ganglia and prefrontal cortex.

To support the hypothesised effect of positive mood that is high in appetitive motivation on left frontal asymmetry, the correlations between changes in positive affect and changes in left frontal asymmetry between the neutral and positive mood inductions will be examined. Hypotheses for this analysis are based on the expected effects of positive mood inductions that are high and low on left frontal asymmetry, and the affective characteristics described for these states (Depue & Collins, 1999). Therefore, it is hypothesised that changes in activated positive affect will be positively correlated with changes in left frontal asymmetry, reflecting an association between increases in activated positive affect and increases in left frontal asymmetry. Again, it is difficult to give a specific hypothesis for the relationship between changes in deactivated positive affect and changes in left frontal asymmetry. However, in line with predictions for the effect of the positive mood induction low in appetitive motivation, it is expected that there will either be no relationship between these variables, or that there will be a negative relationship, such that decreases in deactivated positive affect are associated with increases in left frontal asymmetry.

Another aim of the present study is to indirectly examine the neurobiological mechanisms that may contribute to the influence of positive mood on left frontal asymmetry. Left frontal asymmetry at rest (i.e., in the absence of mood inductions) has previously been found to be related to genetic differences in dopamine activity in the prefrontal cortex (Wacker et al., 2013). However, increases in left frontal asymmetry as a result of positive mood have not previously been examined in relation to dopamine activity. To address this, EBR will also be assessed during neutral and positive mood inductions, and correlations between changes in EBR and changes in left frontal asymmetry (also measured during these inductions) will be examined. As outlined above, Studies 2 and 4 found increases in EBR for the high appetitive mood induction only, which was suggested to reflect greater prefrontal dopamine activity. Therefore, it is hypothesised that there will be a positive correlation between changes in EBR and changes in left frontal asymmetry, such that increases in EBR during mood inductions are related to increases in left frontal asymmetry.

8.2.5. Aims and Hypotheses

1. To examine the effect of positive mood states that are high and low in appetitive motivation on left frontal asymmetry.

i) It is hypothesised that only positive mood that is high in appetitive motivation will result in an increase in left frontal asymmetry.

ii) It is hypothesised that changes in activated positive affect will be positively correlated with changes in left frontal asymmetry, reflecting an association between increases in activated positive affect and increases in left frontal asymmetry.

2. A second aim of the present study is to examine the neurobiological mechanisms that may contribute to left frontal asymmetry, using an indirect physiological measure of dopamine activity (i.e., EBR).

i) It is hypothesised that there will be a positive correlation between changes in EBR and changes in left frontal asymmetry, such that increases in EBR are related to increases in left frontal asymmetry.

8.3. Method

8.3.1. Participants

Forty-four participants (11 males, 31 females; 37 right-handed, 5 left-handed,) aged between 18 and 64 years (M = 36.83 years, SD = 12.95) were recruited and randomly assigned to either a positive mood condition high in appetitive motivation (n = 22) or low in appetitive motivation (n = 22). One participant did not return for the second experimental session, reducing total sample size to N = 43 for within-subjects comparisons, and n = 21 in the appetitive condition.

8.3.2. Measures

8.3.2.1. Mood Induction

All participants completed a neutral mood induction and a positive mood induction that was either high or low in appetitive motivation (see Study 4 for precise methodological details). Inner ear headphones with foam tips were used to minimise interference with EEG recording.

8.3.2.2. Positive Affect

An adapted version of the 12-Point Affect Circumplex Scale (12-PACS; Yik et al., 2011) was used to measure positive affect, with the adjective format and visual analogue response scale. Focus was on the Activation-Pleasure and Deactivation-Pleasure quadrants of the circumplex, with scores collapsed to form Activated Positive Affect and Deactivated Positive Affect factors. Internal consistency for the two factors was demonstrated to be acceptable ($\alpha \geq .061$).

8.3.2.3. EEG Acquisition and Recording

A 19-channel Mitsar-EEG-201 system (two external electrodes attached to the ear lobes) was used for EEG recording. Data was recorded for 8min during the mood induction period, and participants were instructed to keep their eyes open. Data was processed using WinEEG v2.103.70 (using a linked ears reference, 0.3 to 50 Hz band pass filter, and sampling rate of 500 Hz). All electrode impedances (electrode-skin resistance) were under 5000Ω, with homologous sites being within 1000Ω of each other, suggesting conductivity in line with recommended standards (Tatum, 2014).

Obvious muscle artifacts were scored by eye and removed manually, and independent components analysis was conducted to remove ocular artifacts. This enables waveforms to be separated into multiple components reflecting statistically independent sources of signals across channels, based on the kurtosis of the amplitude distribution over time (Jung et al., 2000; Makeig, Debener, Onton, & Delorme, 2004; Vigário, Särelä, Jousmäki, Hämäläinen, & Oja, 2000) Inverse independent components analysis is then used to reconstruct the waveform excluding occular artifacts. A final visual inspection was then conducted, to ensure that excessive data was not removed during the pre-processing stage.

Following pre-processing, a power spectral analysis was conducted offline, using a Fast Fourier Transformation, which deconstructs the composite waveform for each channel into individual sine wave components of different frequencies and amplitudes, that when summed, best match the composite signal. This allows a power spectra to be produced – identification of separate frequency contributions at a single point in time (Harmon-Jones et al., 2010). Data was segmented into two second epochs (time windows) and Hanning window was used to reduce edge artifacts in the non-infinite signal (M. X. Cohen, 2014). As this can result in spectral leakage (data loss at segment boundaries) due to a greater weighting attributed to the central portion of the epoch, epochs were overlapped by 50% (Davidson, Jackson, & Larson, 2000).

After the fast Fourier transformation, average power spectral densities (mV^2/Hz) across all epochs were produced for each channel. From each channel, alpha power (8-13 Hz) spectral densities were extracted and, in line with other studies in the field (Davidson et al., 2000), these were first natural log transformed to correct for a positive skew.

Based on recent studies (e.g., Hughes et al., 2015), power values extracted from channels at sites in the left hemisphere were subsequently subtracted from corresponding values at the right hemisphere (F8-F7 and F4-F3), and are displayed in Figure 8.1.

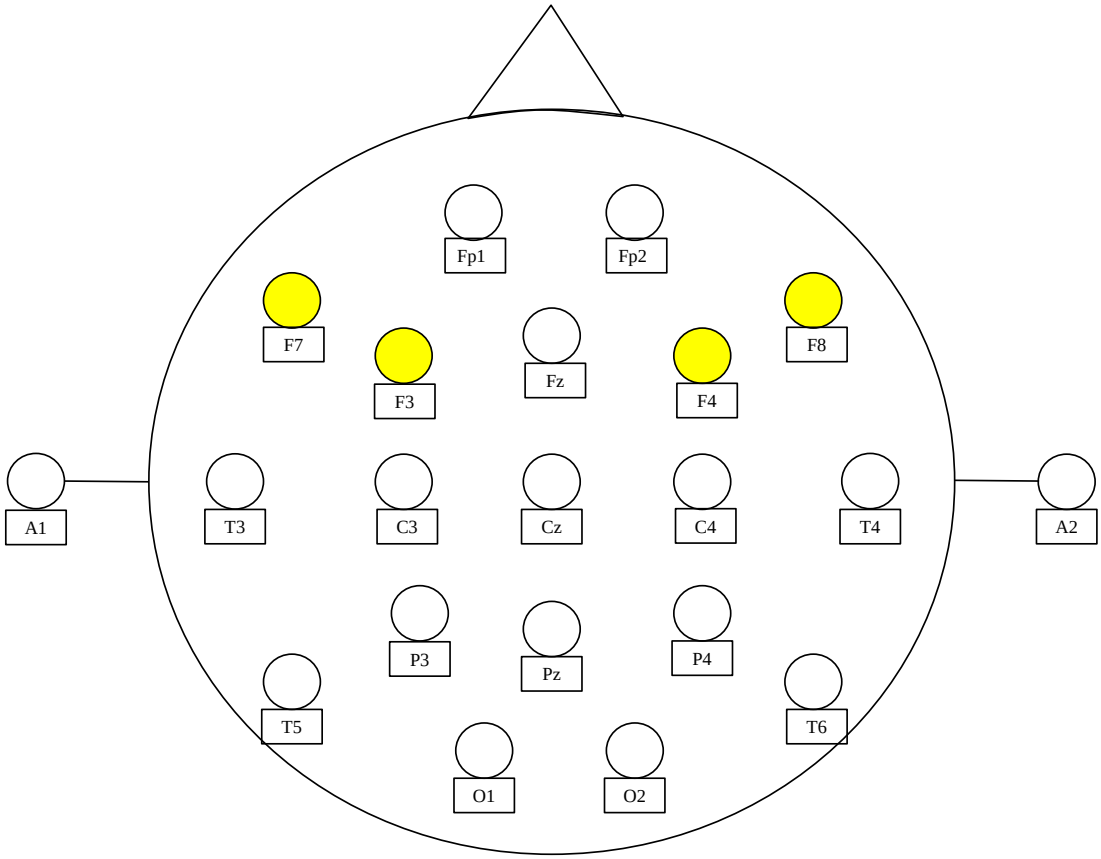


Figure 8.1. *Electrode configuration with highlighted sites of interests.*.

This results in two left frontal asymmetry indexes, where higher values reflect greater left relative to right hemispheric activity (i.e., because alpha power is suggested to be an inverse of cortical activity, Palva & Palva, 2007). These two left frontal asymmetry indexes were then averaged to provide a composite left frontal asymmetry index.

8.3.2.4. EBR

EEG recordings during the mood induction period were visually examined for eye blinks. Low-pass filter was reduced (from 50 Hz) to 15 Hz to remove high frequency activity (Nakanishi et al., 2012). Visual determination of eye blinks was based on sharp increases in the amplitude of the waveform (greater than 100 μV) occurring for less than 500 ms, and high amplitude increases consistent with horizontal eye movements were not counted as blinks (Barbato et al., 2012; Byrne et al., 2015). The first minute was considered to be a period of adaptation and was not included in analysis (Borges et al., 2010). The following 4min were divided into 60sec periods, and the mean number of eye blinks were calculated (cf. Dreisbach et al., 2005). Inter-reliability was found to be good ($r = .97$, $p < .001$) for a randomly selected 10% sample of the data.

8.3.3. Procedure

Participants were required to attend the laboratory for two sessions, and upon entering the laboratory, the researcher prepared the participant for EEG recording. After this, participants completed the 12-PACS, and then the researcher left the room. The computerised mood induction then began, during which EEG was recorded. This was followed by participants completing a second version of the 12-PACS, and then a computerised cognitive task (part of Study 4 and not of interest here). The researcher then re-entered the room, and removed EEG electrodes. The same procedure was followed in both sessions, with the only difference being the mood induction (i.e., one session would be positive and the other would be neutral). The order of mood inductions was counterbalanced across participants, and the order of the 12-PAC versions was counterbalanced within mood inductions. Computerised tasks were presented and timed using Matlab R2014, and the total time for participation in each session was approximately one hour.

8.4. Results

8.4.1. Data Screening

Data screening used the same techniques and followed the same procedures as outlined in the previous chapters. This indicated that all assumptions were met, other than where specified below.

Therefore, data was assumed to be approximately normally distributed for all variables (i.e., a Gaussian distribution was observed on histograms). Although, as outlined above – power values were natural log transformed to correct for a positive skew. There were no outliers (i.e., values were not found to be 1.5 interquartile ranges from the median or to have a z-score 3.29 standard deviations above the mean) and there was also approximately equal variance between groups (i.e., Levene's tests were non-significant).

8.4.2. Mood Induction Check

To summarise results presented in Section 6.4.2, two mixed ANOVAs demonstrated significant time by induction by mood condition interactions for activated and deactivated positive affect (*p*'s < .001).

This was followed by paired t-tests, which found that activated positive affect was increased only for the positive induction in the high appetitive condition, whilst deactivated positive affect was increased only for the positive induction in low appetitive condition (*p*'s < .001). Therefore, these results suggest that the mood inductions were effective.

8.4.3. Effect of Positive Mood on Left Frontal Asymmetry

Three participants were excluded from EEG analysis as impedance was not in line with recommended standards, as this may prevent signals from being reliably attributed to specific electrode locations (Teplan, 2002). This reduced the total sample size to $N = 40$ ($n = 19$ for high appetitive and $n = 21$ for the low appetitive condition).

There were no outliers when the composite left frontal asymmetry index was computed (i.e., F4-F3 and F-F7 values were averaged). However, when examining F4-F3 and F8-F7 asymmetry scores separately, there were two outliers for the F4-F3 index for the neutral induction in the high appetitive condition (one high and one low), and three outliers for the F8-F7 index for the positive induction in high low appetitive condition (all high). These were winsorised to the nearest value, which did not affect the pattern of analysis.

The effect of mood on left frontal asymmetry was examined in relation to the composite left frontal asymmetry index (average of F4-F3 and F8-F7 indexes), as well as separately for the F4-F3 and F8-F7 asymmetry indexes.

To do this, three separate 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVAs were conducted with the composite index, the F4-

F3 index, and the F8-F7 index. Levene's test for homogeneity of variance was significant for left frontal asymmetry during the positive induction for all indexes, suggesting that there may not be equal variances between mood condition groups. However, this should not be problematic for analysis, as ANOVA is generally robust against unequal variances between groups when cell sizes are equal (Zimmerman, 2004).

8.4.3.1. Composite Index

For the composite index, there were no main effects for induction or mood condition (F's = 1.46, p's ≥.233, $\eta^2_p \leq 0.04$). However, the pertinent induction by mood condition did approach significance [$F(1,38) = 3.44$, $p = .071$, $\eta^2_p = 0.08$].

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in left frontal asymmetry within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to two multiple comparisons ($\alpha = .025$) and mean scores are displayed in Figure 8.2.

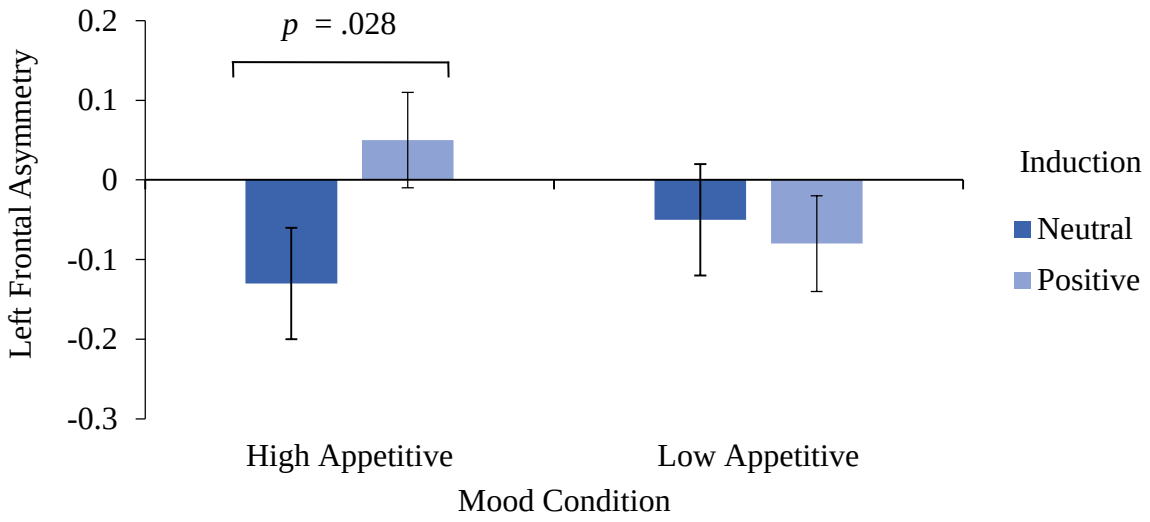


Figure 8.2. *Left frontal asymmetry using composite average index for different inductions within mood conditions. Error bars reflect one standard error above and below the mean. Bonferroni correction for two multiple comparisons (α = .025).*

For the high appetitive condition, Figure 8.2 demonstrates that an increase in left frontal asymmetry was close to significance (M = -0.13, SD = 0.27 vs. M = 0.05, SD = 0.35), [$t(18)$ = 2.03, p = .028, d = 0.58].

For the low appetitive condition, Figure 8.2 demonstrates that there was no significant difference in left frontal asymmetry (M = -0.05, SD = 0.33 vs. M = -0.08, SD = 0.16), [$t(20)$ = -0.49, p = .632, d = -0.12].

Therefore, in line with expectations, there is some evidence that left frontal asymmetry increased only as a result of the positive mood induction for the high appetitive condition.[4]

To confirm that there were no pre-existing differences in left frontal asymmetry between mood conditions, an additional independent t-test was conducted for the composite index in the neutral induction, [$t(39)$ = 0.45, p = .652, d = -0.16].

8.4.3.2. F4-F3 Index

For the F4-F3 index, the main effects for induction and mood condition were not significant [$F(1,38) \leq 2.29$, $p \geq .138$, $\eta^2_p \leq 0.06$], and the pertinent induction by mood condition interaction was also not significant [$F(1,38)$ = 1.30, p = .260, η^2_p = 0.03].

Given the apriori predictions, planned contrasts were conducted using simple effects analysis with paired t-tests to examine left frontal asymmetry for neutral and positive within the different mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to two multiple comparisons (α = .025).

For the high appetitive condition, there was an increase in left frontal asymmetry that approached significance for the positive induction (M = -0.05, SD = 0.14 vs. M = 0.04, SD = 0.23), [$t(18)$ = 1.91, p = .037, d = 0.47].

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[4] To examine whether the effects of positive mood on alpha asymmetry were specific to frontal areas, two separate 2 (induction: neutral/positive) by 2 (mood condition: high appetitive/low appetitive) mixed ANOVAs were conducted with in alpha power composite indexes from posterior (P4-P3) and medial (C4-C3) areas.

For both posterior and medial areas, there were no significant main effects for induction or mood condition [F's $\leq$ 0.32, p's $\leq$ .574, $\eta^2_p \leq$ 0.01] and the induction by mood condition interaction did not reach significance [F's $\leq$ 1.94, p's $\leq$ .173, $\eta^2_p \leq$ 0.05]. However, there was a pattern of increased left frontal asymmetry for the high compared to low appetitive positive mood condition, for both the posterior [(M = .05, SD = .32) to (M = .17 SD = .37) vs. (M = .08, SD = .31) to (M = .01, SD = .33)] and medial composite indexes [(M =.-02, SD = .32) to (M = .01 SD = .38) vs. (M = .01, SD = .31) to (M = -.07, SD = .36)].

Therefore, this suggests that there may be a more general pattern of increased asymmetry across the left hemisphere as a result of positive mood high in appetitive motivation. However, this is most reliably demonstrated in frontal areas, in line with previous research (e.g., Hughes, Yates, Morton, & Smillie, 2015).

For the low appetitive condition, there was no significant difference in left frontal asymmetry for positive and neutral inductions (M = -0.01, SD = 0.21 vs. M = 0.00, SD = 0.13), [$t(20)$ = 0.26, p = .797, d = -0.06].

Therefore, there was evidence of an increase in left frontal asymmetry only for the positive mood induction high in appetitive motivation, although this failed to reach significance following the Bonferroni correction.

To confirm that there were no pre-existing differences in left frontal asymmetry between mood conditions, an additional independent t-test was conducted for the F4-F3 index in the neutral induction, and this was found to be non-significant [$t(34.96)$ = 0.60, p = .553, d = 0.43].

8.4.3.3. F8-F7 Index

For the F8-F7 index, the ANOVA results demonstrated that the main effects of induction and mood condition were not significant [F's ≤ 1.37, $p \geq .249$, $\eta^2_p \leq 0.04$]. However, the pertinent induction by mood condition interaction did approach significance [$F(1,38)$ = 3.29, p = 0.078, η^2_p = 0.08.]

Planned contrasts were conducted using simple effects analysis with paired t-tests to examine changes in left frontal asymmetry within mood conditions. A Bonferroni correction was used to correct for inflated Type I error due to two multiple comparisons (α = .025).

For the high appetitive condition, an increase in left frontal asymmetry for the positive induction approached significance (M = -0.21, SD = 0.44 vs. M = 0.05, SD = 0.50), [$t(18)$ = 1.89, p = .038, d = 0.55].

However, for the low appetitive condition, there was no significant difference in left frontal asymmetry (M = -0.17, SD = 0.22 vs. M = -0.11, SD = 0.44), [$t(20)$ = -0.51, p = .613, d = -0.17].

Again, despite not quite reaching significance, these results demonstrate the expected increase in left frontal asymmetry for the positive mood induction high in appetitive motivation.

To confirm that there were no pre-existing differences in left frontal asymmetry between mood conditions, an additional independent t-test was conducted for the F8-F7 index in the neutral induction, and this was found to be non-significant (M = -0.14, SD = 0.53 vs. M = -0.11, SD = 0.44), [$t(39)$ = 0.19, p = .854, d = 0.06].

8.4.3.4. Relationships between Positive Affect and Left Frontal Asymmetry

The correlations between left frontal asymmetry and positive affect were also explored within neutral and positive inductions at post-induction timepoints, and using change scores (i.e., post- minus pre-induction).

Coefficients and probability values can be seen in Table 8.1, which demonstrates that these were largely non-significant.

Table 8.1. *Correlations between left frontal asymmetry indexes and positive affect*

	Composite Average Index		F4-F3 Index		F8-F7 Index	
	r	*p*	*r*	*p*	*r*	*p*
Neutral Induction						
Post-Induction Activated Affect	.09	.283	-.09	.284	.09	.279
Change in Activated Affect	.21	.091	-.05	.371	.27	.043 *
Post-Induction Deactivated Affect	-.07	.335	-.09	.284	.11	.256
Change in Deactivated Affect	.12	.236	.13	.210	.08	.316
Positive Induction						
Post-Induction Activated Affect	.07	.325	-.07	.342	.14	.196
Change in Activated Affect	.13	.215	-.05	.387	.21	.101
Post-Induction Deactivated Affect	-.05	.391	.13	.219	-.13	.218
Change in Deactivated Affect	-.19	.127	-.02	.452	-.27	.048 *

* $p < .05$

However, for the neutral induction, there was a marginally significant positive correlation between change in activated positive affect and left frontal asymmetry at the F8-F7 index (p = .043), as well as a trend for the composite index (p = .091).

For the positive induction, there was only a marginally significant negative correlation between change in deactivated positive affect and left frontal asymmetry at the F8-F7 index (p = .048).

8.4.4. Effect of Mood on EBR

One participant was removed from EBR analyses due to reporting a medical condition that may have affected visual sensitivity (Barbato et al., 2000). Therefore, N = 42 in this analysis, with n = 20 in the high appetitive condition and n =22 in the low appetitive condition. One value for the positive induction in the low appetitive condition met criteria as an outlier. This was winsorised to the next nearest value (Ghosh & Vogt, 2012), which did not change the overall pattern or significance of results for these analyses.

As presented in Study 4, a mixed ANOVA found a significant induction by mood condition interaction for EBR (p = .044). Paired t-tests demonstrated a greater EBR for the positive induction in the high appetitive condition (p = .025), whilst there was no significant difference between neutral and positive inductions in the low appetitive condition (p = .321).

Therefore, this suggests that appetitive motivation moderates the influence of positive mood on EBR (which coincides with findings of greater left frontal asymmetry as a result of this mood induction in the present study).

This was further supported by findings that EBR was only (positively) related to changes in activated positive affect (p = .006) and activated positive affect at the post-induction time point (p = .011) (presented as part of Study 4).

8.4.5. Changes in Positive Affect, EBR, and Left Frontal Asymmetry

The relationships between changes in positive affect, EBR, and left frontal asymmetry were also examined by calculating change scores (i.e., positive minus neutral). For activated and deactivated positive affect, measurements of affect at the two different timepoints were taken into account [(positive post-induction minus pre-induction) minus (neutral post-induction minus pre-induction)].

Correlations between changes in positive affect, EBR, and left frontal asymmetry are displayed in Table 8.2.

Table 8.2. *Correlations between changes in positive affect, changes in EBR, and changes in left frontal asymmetry indexes*

	Activated Affect	Deactivated Affect	EBR	Composite Index	F4-F3 Index
Activated Affect	-	-	-	-	-
Deactivated Affect	-.56**	-	-	-	-
EBR	.32*	-.17	-	-	-
Composite Index	.22	-.35*	.14	-	-
F4-F3 Index	.02	-.13	.17	.78**	-
F8-F7 Index	.33*	-.42**	.20	.90**	.60**

*$p < .05$, ** $p < .01$.

8.4.5.1. Changes in Positive Affect and Left Frontal Asymmetry

Table 8.2 demonstrates that increases in activated positive affect were significantly correlated with increases in left frontal asymmetry for the F8-F7 index ($p = .020$). This also approached significance for the composite index ($p = .086$), but there was no significant relationship for the F4-F3 index ($p = .137$).

Table 8.2 also demonstrates that increases in deactivated positive affect were significantly correlated with decreases in left frontal asymmetry for the F8-F7 index ($p = .004$) and for the composite index ($p = .013$). Although, again, no significant relationship was found for activated positive affect and the F4-F3 index ($p = .208$).

Therefore, this is in line with hypotheses and suggests that increases in activated positive affect (as experienced during the high appetitive condition) coincide with increases in left frontal asymmetry. It also suggests that increases in left frontal asymmetry coincide with decreases in deactivated positive affect (as experienced during the low appetitive condition), although it should be noted that only a slight numerical decrease in left frontal asymmetry was found during the low appetitive induction.

8.4.5.2. Changes in EBR and Left Frontal Asymmetry

For changes in EBR and left frontal asymmetry, Table 8.2 demonstrates a general pattern in line with hypotheses, such that increases in EBR were related to increases in left frontal

asymmetry for all indexes. However, these relationships were not found to be significant (*p*'s < .195).

Despite this, it is worth noting that there was a correlation between changes in activated positive affect and changes in EBR, such that increases in activated positive affect were associated with increases in EBR [$r(42) = .32$, $p = .020$]. Although, a correlation between changes in deactivated positive affect and changes in EBR did not reach significance, there was a general pattern that increases in deactivated positive affect were associated with decreases in EBR [$r(42) = -.17$, $p = .148$].

Therefore, this is in line with the idea that increases in EBR coincide with increases in activated positive affect.

8.5. Discussion

8.5.1. Positive Mood and Left Frontal Asymmetry

Previous studies have demonstrated that positive mood inductions may increase left frontal asymmetry (i.e., Jones & Fox, 1992; Reeves et al., 1989). However, these findings are not always reliable (Hagemann et al., 1998), which has been suggested to be due to a failure to take into account the motivational intensity of mood states that are induced (Harmon-Jones et al., 2010). Therefore, the present study aimed to examine the effect of positive mood states that were high and low in appetitive motivation on left frontal asymmetry. It was hypothesised that only positive mood high in appetitive motivation would result in an increase in left frontal asymmetry, whilst positive mood that was low in appetitive motivation was expected to have no effect, or possibly result in a decrease in left frontal asymmetry. In line with hypotheses, an increase in left frontal asymmetry was found to occur only for the high appetitive positive induction, whilst the low appetitive positive induction was found to have no effect on left frontal asymmetry.

Prior to the present study, support for the proposition that it is specifically positive mood high in appetitive motivation that results in left frontal asymmetry came from studies conducted by Gable and Harmon-Jones. These studies demonstrated that the brief presentation of appetitive images (i.e., displayed for 12 secs) resulted in an increase in left frontal asymmetry during the period of image presentation (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). Therefore, the current study is the first to indicate that this effect may occur for more enduring positive mood states that are high in appetitive motivation, as opposed to the transient

emotional responses that were likely to have been induced in studies conducted by Gable and Harmon-Jones. Importantly, the present study is also the first to demonstrate that left frontal asymmetry may occur only for positive affect that is high in appetitive motivation, but not for positive affect that is low in appetitive motivation, as no comparison condition (other than to neutral affect) was included in these previous studies.

The studies conducted by Harmon-Jones and Gable also did not include sufficient measures of self-reported affect to validate an association between left frontal asymmetry and positive affect high in appetitive motivation. Specifically, the study conducted by Harmon-Jones and Gable (2009) did not include any measure of affect, whilst Gable and Harmon-Jones (2008a) found that participants reported feeling more "enthusiastic", "pleasant", and "in a good mood" following the presentation of appetitive images. Therefore, this does not provide a clear demonstration of the specific characteristics that are associated with positive affect high in appetitive motivation (i.e., highly activated state of positive affect). However, the present study used a psychometrically tested measure (i.e., the 12-PACS, Yik et al., 2011) to provide a clear demonstration that it was only the high appetitive positive mood induction that resulted in an increase in activated positive affect, whilst the low appetitive mood induction resulted in an increase in deactivated positive affect. This is in line with the affective characteristics that have been described for these states in previous research (Depue & Collins, 1999).

The present study also found some indication that increases in activated positive affect were associated with increases in left frontal asymmetry, but that increases in deactivated positive affect were associated with decreases in left frontal asymmetry. The opposite relationship between changes in activated and deactivated positive affect and left frontal asymmetry is in line with hypotheses. This is also in line with findings of an increase in left frontal asymmetry only for the positive mood induction that was high in appetitive motivation (i.e., which increased activated positive affect), and the assumption that this effect is due to the affective characteristics of this induction. Although the correlations were well-established for the F8-F7 index, these were weaker for the composite asymmetry index. This may reflect the fact that the sample size was small for correlation analysis, reducing statistical power (Wilson Van Voorhis & Morgan, 2007). However, it is more likely that this reflects the failure to find a significant correlation for the F4-F3 index, which is discussed in more detail below.

8.5.2. Left Frontal Asymmetry and Cognitive Control

The finding of greater left frontal asymmetry for only the high appetitive positive induction is in line with Davidson's (1992) suggestion that this effect reflects the lateralisation of the appetitive motivation system. It is proposed that greater left frontal asymmetry for “post-goal” positive affect high in appetitive motivation reflects the active maintenance of goal-relevant representations in working memory (Davidson, 1998). In contrast, “pre-goal” positive affect low in appetitive motivation should be unrelated (or possibly negatively related) to left frontal asymmetry, reflecting the prefrontal cortex being “offline” (i.e., representations are not being actively maintained). This is in line with the suggestions of the motivational intensity model (Gable & Harmon-Jones, 2010), such that positive affect high in appetitive motivation promotes goal-pursuit by facilitating narrower and more stable cognition, whilst positive affect low in appetitive motivation promotes the exploration of new goals and opportunities by facilitating broader and more flexible cognition.

As stated above, the correlations between activated/deactivated positive affect and left frontal asymmetry generally produced more consistent results for the composite asymmetry index and the F7-F8 (compared to F3-F4) index. Although F3, F4, F7, and F8 electrode sites are all located above the lateral prefrontal cortex, F7 and F8 sites are suggested to be located directly above the dorsolateral area of this structure, whilst F3 and F4 electrode sites are suggested to be located at the more mid-lateral prefrontal area (Luppino & Rizzolatti, 2000). Also outlined above, Davidson (1992) suggested that left frontal asymmetry was likely to be related to an increase in the activity in the prefrontal cortex, and specifically the dorsolateral prefrontal cortex. Therefore, more consistent correlations for positive affect and left frontal asymmetry reflected by activity at the F7-F8 index are in line with the suggestion that frontal asymmetry specifically reflects greater activity in the left compared to right dorsolateral area of the prefrontal cortex.

It is important to note that conclusions drawn from EEG recordings, regarding possible underlying neural structures, must be treated with caution, as spatial resolution using this methodology is limited. This is because the cortical current being measured during EEG recording must pass through resistive layers (especially the skull), causing a distorted view of activity when this is examined at the scalp (G. A. Miller, Crocker, Spielberg, Infantolino, & Heller, 2013). However, source localisation techniques can be used to improve the spatial resolution of activity measured using EEG (see Jatoi, Kamel, Malik, Faye, & Begum, 2014, for an overview). Using these techniques, studies have demonstrated that left frontal asymmetry

(assessed at rest) is localised to the dorsolateral prefrontal cortex (Pizzagalli, Sherwood, Henriques, & Davidson, 2005). This is further supported by studies using other methodologies that allow enhanced spatial resolution, such as fMRI (Berkman & Lieberman, 2010). Therefore, future research may use source localisation to examine the specific neural structures underlying the influence of positive affect on left frontal asymmetry.

8.5.3. EBR and Left Frontal Asymmetry

The present study also examined the relationship between changes in left frontal asymmetry and changes in EBR. It was hypothesised that there would be a positive relationship between these variables, such that increases in left frontal asymmetry would be associated with increases in EBR. This was based on the findings from other studies (i.e., Studies 2 and 4) demonstrating an increase in EBR following only the high appetitive mood induction. As only positive mood high in appetitive motivation is proposed to activate the mesocorticolimbic dopamine system (Depue & Collins, 1999), it was suggested that the observed increase in EBR may reflect greater dopamine activity in the prefrontal cortex. The same mechanism has been suggested to underlie findings that positive affect high in appetitive motivation results in an increase in left frontal asymmetry. In line with this suggestion and hypotheses, there was some evidence of a positive relationship between changes in EBR and changes in left frontal asymmetry, but this did not reach statistical significance.

Again, it may be the case that low statistical power may have contributed to the lack of significance for the relationship between changes in EBR and changes in left frontal asymmetry, as sample size was small for correlation analysis (Wilson Van Voorhis & Morgan, 2007). Alternatively, it could be the case that the design of the study prevented a clear demonstration of the relationship between changes in EBR and changes in left frontal asymmetry. Specifically, the temporal effect of mood inductions on left frontal asymmetry is currently unclear. Although studies have demonstrated that positive mood inductions increase left frontal asymmetry when this is assessed during, as well as following, inductions (Coan & Allen, 2004), it could be the case that this effect is best captured in the period following inductions. This may be particularly important when assessing the relationship with EBR, as it could also be the case that the effect of positive mood inductions on this variable is also best reflected in the period of time following inductions. However, the present study assessed both of these variables (i.e., left frontal asymmetry and EBR) during the mood induction period.

Despite the fact that the relationship between changes in EBR and changes in left frontal asymmetry did not reach significance, EBR was found to be greater during the high appetitive positive mood induction, whilst this was not the case for the low appetitive positive mood induction (discussed fully as part of Study 4 in Section 6.5). Thus, the increase in left frontal asymmetry during the high appetitive positive induction did coincide with an increase in EBR as a result of this induction. It is also worth noting that changes in EBR during mood inductions were found to be positively associated with changes in activated positive affect, but negatively associated with changes in deactivated positive affect. Therefore, this provides further evidence that an increase in dopamine activity in the prefrontal cortex (i.e., reflected by a greater EBR) may be related to findings that only positive mood high in appetitive motivation results in an increase in left frontal asymmetry.

Previous research has demonstrated that left frontal asymmetry (assessed at rest) may be related to genetic differences in dopamine activity (e.g., Wacker et al., 2013). There is also evidence linking this to subsequent performance on behavioural reward-based tasks (Hughes et al., 2015), which have been demonstrated to be associated with individual differences in dopamine receptor sensitivity (Treadway et al., 2012). In addition, dopamine receptor density in the left prefrontal cortex has been demonstrated to predict enhanced learning from reward (Tomer et al., 2014). Therefore, these studies have linked individual differences in left frontal asymmetry to dopamine activity in the prefrontal cortex. However, the current study is the first to provide evidence that an increase in dopamine activity (possibly in the prefrontal cortex) may underlie findings that positive affect high in appetitive motivation results in greater left frontal asymmetry (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009).

Neurobiological models of cognitive control postulate that the stabilisation of representations in working memory is facilitated by an increase in dopamine levels, resulting in a tonic D1 dominated state, in the prefrontal cortex (Durstewitz & Seamans, 2008). However, updating of representations and the flexible switching of attention is proposed to occur due to an increase in dopamine levels in the basal ganglia. This is argued to inhibit the tonic activity of D2 neurons and/or stimulate the phasic activity of D1 neurons, which ultimately allows new information entry into working memory (Frank & O'Reilly, 2006). Therefore, a positive relationship between changes in EBR and changes in left frontal asymmetry may reflect increased D1 dominated activity in the left prefrontal cortex. The is in line with suggestions from the motivational intensity model (Gable & Harmon-Jones, 2010), in relation to the influence of

positive affect high in appetitive motivation on cognition, if this is assumed to increase dopamine levels in the prefrontal cortex.

Interestingly, it is specifically tonic D1 dopamine activity in the dorsolateral prefrontal cortex that has been previously associated with stability in cognitive control. For example, this area has been found to be activated during the active maintenance of a simple cue over a delay period (Barch et al., 1997), and D1 receptor availability in the dorsolateral prefrontal cortex has been demonstrated to be related to performance on working memory tasks requiring active maintenance (Abi-Dargham et al., 2002). Therefore, this is in line with findings of the current study, which demonstrated that correlations between changes in left frontal asymmetry and activated/deactivated positive affect were most reliable for the F7-F8 index. Therefore, this suggests that an increase in left frontal asymmetry for positive mood that was high in appetitive motivation may be related to greater mesocorticolimbic dopamine activity and elevated levels of D1 dopamine activity, specifically in the left dorsolateral prefrontal cortex.

8.5.4. Motivational Intensity Model

Positive affect high in appetitive motivation has consistently been demonstrated to result in a narrower attentional scope (i.e., resulting in a more local bias on Navon letter tasks, and a reduced breath of spatial attention on Flanker tasks) (Gable & Harmon-Jones, 2008b). The suggestion that left frontal asymmetry may be associated with these effects was supported in a study conducted by Harmon-Jones and Gable (2009), which found that positive affect high in appetitive motivation increased left frontal asymmetry, as well as resulted in a narrower attentional scope (i.e., more local bias). This suggests that left frontal asymmetry may be associated with the effects of positive affect on attentional scope, although it should be noted that this study again examined the effects of only briefly presented appetitive images (during the short period of time following image presentation), and effects were also not examined in relation to changes in positive affect as a result of this manipulation.

Positive affect that is high in appetitive motivation has also been found to influence performance on tasks that assess the balance between flexibility and stability in cognitive control. For example, Liu and Wang (2014) found that positive affect high in appetitive motivation resulted in reduced flexibility (i.e., greater stability) on Dreisbach and Goschke's (2004) set-shifting paradigm. However, this was not found to be the case in either of the studies conducted in the current research, which examined performance on this paradigm during a positive mood induction that was high in appetitive motivation (i.e., Studies 3 and 4).

Furthermore, the data for the present study was collected within the same experiment as Study 4, in which the set-shifting task was completed by participants. However, when examined, this study did not demonstrate a reduction in flexibility following the positive mood induction high in appetitive motivation, and there were also no significant effects or associations for left frontal asymmetry and set-shifting performance.

Greater stability in cognitive control has been demonstrated to occur when participants are offered performance-based reward incentives on the AX-CPT (e.g., Frober & Dreisbach, 2014). One recent study examined the effect of positive mood inductions that could be described as high and low in appetitive motivation on left frontal asymmetry and AX-CPT performance (Wacker, 2017). However, the mood inductions were not found to have the expected effects on affect, which may explain weak effects on AX-CPT, and no effects in relation to left frontal asymmetry. Despite this, there was some evidence of a positive relationship between stability on the AX-CPT and left frontal asymmetry, although this was not consistently observed. No effect was found for positive mood inductions high and low in appetitive motivation on the AX-CPT in the current research (Study 5), but this too may have been due to the mood induction being less effective than expected. Therefore, future work should examine links between positive mood high in appetitive motivation, frontal asymmetry, and AX-CPT performance.

However, the current research did find that only positive mood high in appetitive motivation resulted in attenuated performance on a creativity task that required divergent thinking (i.e., Study 4), which involves cognitive flexibility, in terms of producing many diverse solutions to a problem. This study also found enhanced divergent thinking task performance for positive mood low in appetitive motivation. Therefore, these results were in line with the motivational intensity model (i.e., positive mood high in appetitive motivation results in narrower and more stable cognition, whilst broader and more flexible cognition occurs for positive mood low in appetitive motivation) (Gable & Harmon-Jones, 2010). Therefore, it would be interesting to examine the effects of positive mood inductions that are high and low in appetitive motivation on left frontal asymmetry and performance on this task. Furthermore, these aims could also be examined in relation to performance on a creativity task that requires convergent thinking, which involves cognitive stability, to evaluate the ultimate solution to a problem.

8.5.5. Conclusions

The present study examined the moderating role of appetitive motivation in relation to the influence of positive mood on left frontal asymmetry. In line with hypotheses, positive mood high in appetitive motivation resulted in an increase in left frontal asymmetry, whilst no effect was observed for positive mood low in appetitive motivation. Previous studies have only demonstrated this effect following the brief presentation of appetitive images (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). Therefore, the present study extends these findings in several important ways: i) left frontal asymmetry is also increased for more enduring mood states high in appetitive motivation; ii) this effect occurs only for positive mood high in appetitive motivation and not for positive mood low in appetitive motivation; iii) this is corroborated by a clear demonstration that increases in left frontal asymmetry were accompanied by an increase in only activated (not deactivated) positive affect.

There was also evidence of a positive correlation between changes in activated positive affect and changes in left frontal asymmetry and a negative correlation between changes in deactivated positive affect and left frontal asymmetry. This is in line with hypotheses and suggests that increases in left frontal asymmetry were associated with increases in activated positive affect, but decreases in deactivated positive affect. Therefore, this supports the assumption that the increase in left frontal asymmetry for the positive induction high in appetitive motivation was due to an increase in activated positive affect. Overall, these results are in line with Davidson's (1992) suggestion that the effect of positive mood on left frontal asymmetry reflects the lateralisation of the appetitive motivation system to the left prefrontal cortex. This is proposed to be beneficial for the pursuit of reward or appetitive goals because it facilitates the active maintenance of goal-relevant representations in working memory.

The present study also considered the possible neural mechanisms that may contribute to left frontal asymmetry. To do this, correlations between changes in EBR and changes in left frontal asymmetry were examined. In line with hypotheses (although not statistically significant), a pattern towards a positive relationship was observed, suggesting that increases in left frontal asymmetry were associated with increases in EBR. This suggests that increases in EBR contribute to the effect of positive mood high in appetitive motivation on left frontal asymmetry. Neurobiological models suggest that stability in cognitive control is due to an increase in dopamine in the prefrontal cortex, resulting in greater tonic D1 activity (Durstewitz & Seamans, 2008). Therefore, it may be suggested that greater left frontal asymmetry as a result of positive affect high in appetitive motivation may reflect this activity. Interestingly,

results of the current study were found to be most reliable for the F7-F8 index, which may reflect activity specifically in the dorsolateral prefrontal cortex, which has previously been related to stability in cognitive control (i.e., Barch et al., 1997).

9. General Discussion

This chapter will summarise and integrate the results and conclusions from Studies 1-6. These studies aimed to examine the role of appetitive motivation in relation to the influence of positive mood on cognition. The research rationale was guided by the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect *low* in appetitive motivation results in broader and more flexible cognition to facilitate exploratory behaviour, and allows an individual to build upon personal resources (Fredrickson, 1998). In contrast, this model suggests that positive affect *high* in appetitive motivation results in narrower and more stable cognition, which facilitates focus on the pursuit of rewards (or appetitive goals). Therefore, Studies 1 and 2 examined the influence of positive mood states, that were high or low in appetitive motivation, on more complex cognitive processes (i.e., divergent and convergent thinking in creativity). In contrast, Studies 3, 4, and 5 examined the influence of these divergent positive mood states on more basic and fundamental cognitive processes (i.e., the balance between flexibility and stability in cognitive control).

An additional aim of the current research was to examine the possible neurobiological mechanisms underlying the influence of positive mood on cognition, using an indirect physiological measure of dopamine activity (i.e., EBR). This was based on the neuropsychological theory of positive affect (Ashby et al., 1999), which proposed that positive affect results in broader and more flexible cognition due to increases in dopamine activity in the mesocorticolimbic and nigrostriatal pathways. However, neurobiological models of cognitive control suggest that, whilst increases in dopamine activity in the nigrostriatal pathway may result in greater flexibility in cognitive control (Frank & O'Reilly, 2006), increases in dopamine activity in the mesocorticolimbic pathway may result in greater stability in cognitive control (Durstewitz & Seamans, 2008). Furthermore, positive affect that is high in appetitive motivation is proposed to result in increases in dopamine activity in the mesocorticolimbic pathway, whilst positive affect that is low in appetitive motivation is proposed to result in an increase in activity in separate neural substrates (Depue & Collins, 1999).

The neuropsychological theory of positive affect (Ashby et al., 1999) has received support from previous findings indicating that a positive mood induction resulted in greater flexibility in cognition, as well as an increase in EBR (Chermahini & Hommel, 2012). It was suggested that this increase in EBR reflected greater dopamine activity specifically in the nigrostriatal

pathway. However, pharmacological studies have demonstrated that manipulations targeting dopamine activity in the nigrostriatal and mesocorticolimbic pathways both increase EBR (Elsworth et al., 1991). As the mesocorticolimbic pathway has previously been associated with positive affect that is high in appetitive motivation (Depue & Collins, 1999), the influence of positive mood states that were high or low in appetitive motivation were examined in relation to EBR in Studies 1, 2, 4, and 5. Furthermore, the influence of positive mood on flexibility has been demonstrated to depend on pre-existing individual differences in EBR (Chermahini & Hommel, 2012). Therefore, Studies 1 and 2 also examined the relationship between EBR and divergent and convergent thinking in creativity, as well as whether individual differences in EBR moderated the influence of positive mood on these processes. Studies 4 and 5 examined these aims in relation to the balance between flexibility and stability in cognitive control.

A final research aim addressed the suggestion that the appetitive motivational system may be lateralised to the left prefrontal cortex (Davidson, 1992). This is supported by studies demonstrating that positive mood inductions result in greater left frontal asymmetry in the alpha band, assessed using EEG (N. A. Jones & Fox, 1992; Reeves et al., 1989). However, other attempts to replicate these findings have produced inconsistent results (e.g., Hagemann et al., 1998). Harmon-Jones et al. (2010) suggested that this may be due to a failure to consider the motivational intensity of positive mood inductions, as more consistent results have been found for studies using appetitive stimuli (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). Therefore, Study 6 examined the differential influence of positive mood states that were high or low in appetitive motivation on left frontal asymmetry. Furthermore, greater left frontal asymmetry at rest is suggested to be related to greater mesocorticolimbic dopamine activity. This is in line with findings that left frontal asymmetry at rest is greater for those individuals with genetic differences associated with increased dopamine activity in the prefrontal cortex (e.g., Wacker et al., 2013). Therefore, Study 6 also examined the relationship between changes in left frontal asymmetry and changes in EBR following mood inductions.

9.1. Overview of Findings

9.1.1. Creativity

Study 1 examined the influence of positive mood states that were high and low in appetitive motivation on divergent and convergent thinking processes in creativity. Based on descriptions of the affective characteristics associated with these states (Depue & Collins, 1999), it was expected that positive mood that was high in appetitive motivation would result only in an

increase in activated positive affect, whilst positive mood that was low in appetitive motivation would result only in an increase in deactivated positive affect. However, this was not found to be the case, which was surprising as the mood inductions were adapted from previous studies demonstrating effective changes in activated and deactivated positive affect (e.g., Smillie et al., 2012). It was suggested that this may have been due to a combination of methodological factors, most notably the complex design, which may have resulted in fatigue for participants and a failure to engage in the mood induction. In addition, the UMACL (Matthews et al., 1990), with the use of a brief Likert scale, may not have been sensitive to mild changes in positive affect. This may not have allowed a clear assessment of deactivated positive affect, as this was assessed using the Hedonic Tone factor, which only takes into account the valence, and not the activation component of deactivated positive affect.

The failure of the mood inductions to induce the expected changes to positive affect may explain the finding that these inductions had no effect on convergent or divergent thinking processes in this study. However, there was a trend towards a negative relationship between divergent thinking and activated positive affect, which is in line with the expectation that positive mood high in appetitive motivation would be detrimental for divergent thinking, as this requires broader and more flexible cognition. However, a similar trend was also observed for convergent thinking, which is assumed to require narrower and more stable cognition. This is not in line with the assumption that positive mood high in appetitive motivation would have opposite effects on divergent and convergent thinking processes. One possible explanation may be that this relationship reflects the fact that the Remote Associates Test (used to assess convergent thinking in Study 1) may include a component of divergent thinking (C. S. Lee et al., 2014). Therefore, future studies in this area may want to examine the effect of positive mood that is high in appetitive motivation on more traditional measures of convergent thinking, such as IQ tests.

Taking into account the methodological limitations of Study 1, Study 2 focused on the influence of positive mood states that were high and low in appetitive motivation only on divergent thinking in creativity. The modified mood induction procedures were found to have the expected effect on activated and deactivated positive affect, suggesting that these inductions were able to induce effectively the characteristics associated with these distinct positive mood states (Depue & Collins, 1999). In line with hypotheses, divergent thinking performance was found to be significantly enhanced only as a result of the positive mood induction that was low in appetitive motivation, whilst performance was found to be significantly reduced as a result

of the positive mood induction high in appetitive motivation. This was further supported by the finding of a slight non-significant trend towards a positive relationship between deactivated positive affect (i.e., associated with the low appetitive condition) following the positive mood inductions and divergent thinking. This is complimentary to the negative trends observed between activated positive affect (i.e., associated with the high appetitive condition) at both pre- and post-induction timepoints and divergent thinking in Study 1.

9.1.1.1. Creativity and EBR

Studies 1 and 2 also examined the effect of positive mood inductions that were high or low in appetitive motivation on EBR. No changes in EBR were observed for either of these mood inductions in Study 1, which was likely due to the lack of effectiveness that was demonstrated for inductions. This is supported by the fact that for Study 2 (in which inductions were demonstrated to be effective) the effect of the positive mood inductions on EBR was moderated by appetitive motivation, such that EBR was increased for positive mood high in appetitive motivation, but decreased for positive mood low in appetitive motivation. This was corroborated by findings of a slight, albeit non-significant trend, towards a positive relationship between activated positive affect at the post-induction timepoint and EBR during the positive mood inductions. It should be noted that a negative relationship was found between EBR and both activated and deactivated positive affect in Study 1. However, this was observed prior to mood inductions only. The failure to find a positive relationship between activated positive affect and EBR post-mood inductions in Study 1 may have been due to ineffective mood induction procedures.

The relationship between individual differences in EBR and creativity was also examined in Study 1 prior to the mood induction. This was based on Chermahini and Hommel's (2012) finding that EBR was related to divergent thinking in an inverted U-shape at baseline, and to convergent thinking in a negative linear relationship. However, there was no evidence of either quadratic or linear relationships between EBR and divergent or convergent thinking in Study 1. The failure to find an inverted U-shaped relationship between EBR and divergent thinking was also replicated in Study 2, when this was examined for the neutral induction. Instead, a negative linear relationship was found between these variables. The failure to find an inverted U-shaped relationship in this study could be because the sample size was small for this type of analysis (K. R. Murphy et al., 2014). However, a much larger sample size was used in Study 1, and an inverted U-shaped relationship was also not observed. Furthermore, Chermahini and

Hommel (2012) have previously demonstrated this relationship with a sample size that was similar to that used in Study 2.

Chermahini and Hommel (2012) also found that increases in EBR as a result of a positive mood induction were correlated with increases in divergent thinking. However, a trend towards a negative correlation between changes in EBR and changes in divergent (and convergent) thinking were found in Study 1, suggesting that increases in EBR were related to decreases in divergent thinking. This is also in line with the negative relationships that were found between EBR and divergent thinking at baseline in Study 1 (i.e., prior to mood inductions) and Study 2 (during the neutral mood induction). Chermahini and Hommel (2012) found that the effect of the positive mood induction on divergent thinking was moderated by individual differences in EBR, such that only those with a lower EBR (i.e., in positive slope of the inverted U-shaped relationship with divergent thinking) were found to have enhanced performance following the mood induction. However, there was no evidence that individual differences in EBR moderated divergent thinking performance in Study 1 or Study 2. Therefore, this is in line with the failure to find an inverted U-shape at baseline in these studies.

One possible explanation for the failure to find the inverted U-shaped relationship between baseline EBR and divergent thinking, as was observed by Chermahini and Hommel (2010, 2012), may be due to a lower median EBR in the current research. Although median EBR was not reported by Chermahini and Hommel (2010, 2012), it can be estimated from visual examination of the scatterplots presented in these studies. This seems to be considerably lower compared to both Studies 1 and 2, which may result in the samples in these studies being situated in the negative slope of an inverted U-shaped relationship between baseline EBR and divergent thinking (i.e., as observed by Chermahini & Hommel, 2010, 2012). However, it is unclear why there may be differences between median EBR, as samples in Studies 1 and 2 were comparable in terms of age, gender, and cultural norms (i.e., both conducted at Western universities) to samples used by Chermahini and Hommel (2010, 2012). Although, one possible explanation may be that there were differences in terms of intelligence, which has been related to dopamine activity (Previc, 1999).

9.1.2. Flexibility in Cognitive Control

Using Dreisbach and Goschke's (2004) attentional set-shifting paradigm, Studies 3 and 4 examined the influence of positive mood states that were high or low in appetitive motivation on flexibility in cognitive control. The original paradigm included two switch conditions. A

perseveration condition required participants to shift attention to a novel target and ignore the previously relevant colour that is now the distractor. A *distraction* condition required participants to shift attention to the previously irrelevant colour and ignore a novel distractor. Liu and Wang (2014) demonstrated that positive affect low in appetitive motivation, resulted in an increase in switch costs in the perseveration condition but a decrease in the distraction condition, whilst positive affect high in appetitive motivation resulted in the opposite pattern of results. Therefore, whilst positive affect low in appetitive motivation resulted in greater flexibility at the cost of increased distractibility, presumably due to an increased novelty bias, positive affect high in appetitive motivation resulted in reduced flexibility and decreased distractibility, presumably due to a decreased novelty bias.

However, despite mood inductions that were shown to produce the expected changes in positive affect (Depue & Collins, 1999), Study 3 failed to produce findings in line with those observed by Liu and Wang (2014). Previous studies demonstrating effects of positive affect on performance in this set-shifting paradigm, have briefly presented appetitive images prior to each trial (e.g., Dreisbach & Goschke, 2004; Liu & Wang, 2014). This likely induces transient emotional responses, whilst more enduring mood states were induced in the current research. As mood states have been described as less intense and more diffuse than transient emotional responses (Ekman, 1992; Frijda, 1993), it may be the case the effects on cognitive control are weaker, resulting in the null effects. In addition, Study 3 also aimed to further investigate the suggestion that an increased/decreased bias towards novelty may underlie the effects of positive affect on this paradigm. Therefore, adaptions to the original set-shifting paradigm may also have contributed to null results.

Specifically, two new switch conditions were added to the original paradigm. In an *engaging novel* condition, the target became a novel colour but the distractor remained unchanged, whilst in an *ignoring novel* condition, the target remained unchanged and the distractor became a novel colour. Therefore, processes related to engaging and ignoring novelty in perseveration and distraction conditions were isolated respectively. However, the inclusion of these new conditions may have diluted the effects of mood on the original switch conditions (e.g., with fewer switch trials per condition) resulting in null findings. In addition, "novel-probe" trials were also presented within each pre-switch blocks of trials, to isolate processes related to ignoring novelty. These may have been distracting (resulting in a detriment to performance), or may have caused participants to become more alert to switches (resulting in a benefit to

performance). Therefore, these general effects on performance may have also masked any effects on switch costs as a result of the mood inductions.

High and low appetitive inductions were not found to have any effect on the new ignoring novel switch condition, or pre-switch novel-probe trials. However, both positive mood inductions were found to decrease switch costs in the new engaging novel switch condition. This was surprising, as it was expected that only positive mood low in appetitive motivation would have this effect, as enhanced performance in this condition reflects greater flexibility in cognitive control. Instead, this suggests that both positive mood high and low in appetitive motivation result in greater flexibility, which is potentially due to an increased novelty bias. This complementary effect (distraction by novelty) for these mood inductions may not have been evident on the ignoring novelty switch condition or on novel-probe trials, as these did not involve a switch in attention per se (i.e., participants continued to respond to the same target stimulus following the "switch"). Therefore, it may be the case that such effects of positive mood are only apparent when a switch in attention, and the associated demand on cognitive control, is required.

As the inclusion of new switch conditions may have contributed to null results in Study 3, Study 4 examined the influence of positive mood states that were high or low in appetitive motivation on only the original set-shifting conditions. Although no significant effects were observed for positive mood low in appetitive motivation, there was a general pattern towards greater flexibility following this induction (i.e., switch costs were found to be decreased in the perseveration condition, but increased in the distraction condition). This pattern replicates the effects observed by Liu and Wang (2014), who used affective images, presented briefly prior to each trial on the set-shifting paradigm, to induce positive affect low in appetitive motivation. Therefore, as outlined above, it may be the case that the effects of more enduring positive mood states (i.e., elicited by mood inductions prior to the set-shifting task in the current research) may be in line with transient emotional responses (i.e., elicited by Liu & Wang, 2014). However, these effects may be weaker, because these states are less intense and more diffuse (resulting in only a general pattern towards greater flexibility in Study 4).

In contrast, positive mood high in appetitive motivation was demonstrated to have a general, albeit statistically non-significant, detrimental effect on performance (i.e., switch costs were increased in both the perseveration and distraction conditions). This does not replicate previous effects observed when positive images high in appetitive motivation were presented prior to each trial, as switch costs were found to be increased in the perseveration, but decreased in the

distraction condition, suggesting reduced flexibility and decreased distractibility (Liu & Wang, 2014). There was some indication that positive mood high in appetitive motivation might have led to increased stability during pre-switch trials (i.e., reduced compatibility effects for this condition), but this does not account for a general detrimental effect on performance following the switch. However, this pattern of results mirrors the effects of a lower working memory capacity on this set-shifting paradigm (Tharp & Pickering, 2011). Therefore, it could be suggested that positive mood high in appetitive motivation may have simply reduced working memory capacity, resulting in the general detrimental effect on cognitive control.

9.1.2.1. Flexibility in Cognitive Control and EBR

Study 4 also examined the effect of positive mood inductions that were high and low in appetitive motivation on EBR. In line with results of Study 2, an increase in EBR was found for the high appetitive induction, although a decrease in EBR for the low appetitive induction did not reach significance. There was no evidence of (liner or quadratic) relationships between baseline EBR and switch costs during the neutral induction, and baseline EBR did not moderate set-shifting performance during the neutral induction, contrary to previous studies where higher EBR was associated with greater flexibility (Dreisbach et al., 2005; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011). It was suggested that null results here may possibly reflect the fact that previous studies have assessed individual differences in EBR at baseline, whilst Study 4 assessed this during in the neutral mood induction, which could have affected EBR. Alternatively, it could be the case that a relationship between EBR and switch costs only emerges following the positive mood inductions.

However, EBR during both the neutral and positive inductions was found to be negatively correlated with distractor compatibility effects, suggesting that greater EBR was related to enhanced distractor inhibition. Furthermore, EBR in the neutral induction was found to moderate the effect of positive mood on switch costs, such that only those with a higher EBR demonstrated attenuated performance on both switch conditions following the high appetitive positive induction. Therefore, this suggests a possible non-linear U-shaped relationship between baseline EBR and generally greater stability or effortful control (i.e., reduced flexibility) on this task. This implies that only those individuals with a level of dopamine activity that is above the median at baseline (i.e., during the neutral induction) display greater stability or effortful control, resulting in increased switch costs, following the high appetitive positive mood induction. However, this effect needs to be interpreted with caution, as a

quadratic relationship was not observed at baseline (and baseline EBR was not found to moderate set-shifting performance), and cell size was low for this analysis.

9.1.3. Stability in Cognitive Control

Study 5 used the AX-CPT to examine the influence of positive mood states that were high and low in appetitive motivation on stability in cognitive control. Positive images (assumed to be low in appetitive motivation) presented prior to each trial on the AX-CPT have been demonstrated to reduce stability in cognitive control. Specifically, studies have found that performance (assessed using RTs and error rates) is enhanced on AY trials, but attenuated on BX trials (e.g., Dreisbach, 2006). This is suggested to reflect reduced stability in cognitive control because this is detrimental to performance on AY trials, as active maintenance of the A cue is associated with the incorrect response when the B probe is presented. However, this is beneficial to performance on BX trials, as active maintenance of the B cue is associated with the correct response when the X probe is presented. There was some evidence of a similar effect for positive mood low in appetitive motivation in Study 5, as error rate was found to be reduced only on AY trials.

In contrast to positive affect, performance-dependent reward incentives have previously been demonstrated to result in faster RTs across all trial-types, but increased error rate only on AY trials (e.g., Frober & Dreisbach, 2014). This was suggested to reflect greater stability in cognitive control, as an increase in RTs on all trial-types may reflect enhanced task preparation, whilst error rate may be increased only on AY trials, as this is the only cue-probe condition that enhanced active maintenance may be detrimental for performance. However, Study 5 did not find a pattern of results in line with those observed for reward incentives in previous studies. Instead, RTs were found to be slower and error rates were lower across all trial-types for positive mood high in appetitive motivation. This suggests that this induction may have resulted in the prioritisation of accuracy over speed in responding (i.e. a greater response-threshold). Further support comes from the observation of trends towards a positive relationship between RTs and activated positive affect (i.e., associated with the high appetitive condition) at the post-induction timepoint and when change scores were calculated.

9.1.3.1. Stability in Cognitive Control and EBR

Study 5 also examined the effect of mood inductions that were high and low in appetitive motivation on EBR. In contrast to Studies 2 and 4, these mood inductions were not found to

have any effect on EBR. One explanation for this disparity may be due to the fact that the mood induction high in appetitive motivation was not found to be as effective at increasing activated positive affect as was demonstrated in Study 2 and 4. Another explanation may involve the use of a between-subjects design, as both previous studies used within-subject designs to examine the effect of mood inductions on EBR. Therefore, it may be important to take into account pre-existing individual differences in EBR when examining the influence of positive mood inductions. The relationship between EBR and performance on the AX-CPT was also examined and it was expected that EBR would be differentially related to performance on AY and BX trials. However, there was no evidence of this when the possibility of both linear and quadratic relationships were examined. In addition, there was also no evidence that EBR moderated performance on the AX-CPT, or that this moderated the influence of positive mood on performance.

9.1.4. Left Frontal Asymmetry

The effect of positive mood inductions that were high or low in appetitive motivation on left frontal asymmetry in alpha power was assessed in Study 6. Appetitive motivation was found to moderate the influence of positive mood on left frontal asymmetry, such that this increased only for the positive mood induction high appetitive motivation. In contrast, the positive mood induction low in appetitive motivation was found to result in a numerical (but non-significant) decrease in left frontal asymmetry. This was further supported by evidence that increases in activated positive affect (i.e., as experienced in the high appetitive condition) were related to increases in left frontal asymmetry, whilst increases in deactivated positive affect (i.e., as experienced in the low appetitive condition) were related to decreases in left frontal asymmetry. This is in line with previous studies demonstrating similar effects for briefly presented appetitive images (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009). Therefore, this helps to explain inconsistency in findings from earlier studies examining the influence of positive mood on left frontal asymmetry (Harmon-Jones et al., 2010), and suggests that it is important to take into account the motivational intensity of positive mood induced.

9.1.4.1. Left Frontal Asymmetry and EBR

Study 6 also examined the relationship between changes in EBR and changes in left frontal asymmetry. Although there was some evidence of a positive relationship between changes in EBR and changes in left frontal asymmetry, this did not reach statistical significance. Low

statistical power may have contributed to the lack of significance for this relationship, as sample size was small for correlation analysis (Wilson Van Voorhis & Morgan, 2007), especially when using difference scores (Edwards, 2001). The design of the study may have also contributed to lack of significance here, as the temporal effect of mood inductions on left frontal asymmetry and EBR is currently unclear (i.e., effects could occur immediately, or may be best reflected in the period following the inductions). As the effect of mood inductions on these variables could follow different time courses, this may have resulted in weaker correlations. Furthermore, changes in EBR and left frontal asymmetry were calculated between neutral and positive inductions in different experimental sessions. EBR has previous been demonstrated to be affected by factors that may have varied between these session, such as sleep duration and illness (Barbato et al., 2000). This may have reduced the reliability of EBR, and resulted in a weaker correlation with changes in left frontal asymmetry.

Although changes in EBR were not found to be significantly correlated with changes in left frontal asymmetry, the positive mood induction high in appetitive motivation was found to result in a significant increase in EBR, which was not the case for the positive mood induction low in appetitive motivation (as reported in Study 4). Therefore, increases in left frontal asymmetry during the high appetitive positive mood induction did coincide with increases in EBR in Study 6. It is also worth noting that changes in EBR were positively associated with changes in activated positive affect (i.e., as experienced in the high appetitive condition), but negatively associated with changes in deactivated positive affect (i.e., as experienced in the low appetitive condition). However, the finding of a significant increase in left frontal asymmetry and EBR during the high appetitive positive mood induction undermines the lack of significance for correlations between changes in these variables being due to variation in the time courses of these effects.

9.2. Implications

9.2.1. The Motivational Intensity Model

Studies 1 and 2 are the first to examine the moderating role of appetitive motivation in relation to the influence of positive mood on creativity. Although Study 1 did not provide support for the motivational intensity model (Gable & Harmon-Jones, 2010), as no effects were observed for positive mood on creativity, this was likely due to the failure of the mood inductions to induce the expected changes in positive affect. In contrast, Study 2 did provide support for this model, as appetitive motivation was found to moderate the influence of positive mood on

divergent thinking performance. This was such that positive mood low in appetitive motivation enhanced divergent thinking performance, whilst positive mood high in appetitive motivation resulted in attenuated performance. Therefore, this is in line with the directional predictions of the motivational intensity model, such that positive mood that was low in appetitive motivation promoted broader and more flexible cognition (i.e., was beneficial for divergent thinking), whilst positive mood high in appetitive promoted narrower and more stable cognition (i.e., was detrimental for divergent thinking).

The motivational intensity model (Gable & Harmon-Jones, 2010) was originally supported by evidence that positive affect low in appetitive motivation resulted in a broader attentional scope, whilst positive affect high in appetitive motivation resulted in a narrower attentional scope (Gable & Harmon-Jones, 2008b). However, this was expanded to apply to the balance between flexibility and stability in cognitive control by Liu and Wang's (2014) findings that positive affect low in appetitive motivation resulted in greater flexibility on Dreisbach and Goschke's (2004) set-shifting paradigm, whilst positive affect high in appetitive motivation resulted in reduced flexibility (i.e., greater stability). Positive affect in this study was induced by briefly presenting affective images prior to each trial. However, Study 3 found no significant effects for more enduring positive mood states that were high and low in appetitive mood induction. While differences in methods used, as a result of adaptations of the set-shifting paradigm, may have contributed to the failure to replicate Liu and Wang's findings, the general pattern of results were similar (rather than divergent) across both mood conditions, which is not in line with the motivational intensity model.

Study 4 re-examined the influence of more enduring mood states on the original set-shifting paradigm (i.e., in the absence of adaptations). Although not significant, there was a general pattern towards greater flexibility (i.e., switch costs were found to be increased in the perseveration condition, but decreased in the distraction condition) when the positive mood induction was low in appetitive motivation. Therefore, this is in line with the motivational intensity model (Gable & Harmon-Jones, 2010). In contrast, the positive mood induction high in appetitive motivation was found to result in increased switch costs across both the perseveration and distraction conditions, suggesting a general detrimental effect on task performance. This is not in line with the motivational intensity model, which suggests that positive mood high in appetitive motivation promotes greater stability (i.e., reduced flexibility) in cognitive control (i.e., switch costs would be expected to increase in the perseveration condition, but decrease in the distraction condition).

It was suggested that greater switch costs in both condition may reflect a general increase in effortful control and working memory load induced by the high appetitive mood induction. As the induction was temporally distinct from the task demands, this may not have facilitated the maintenance of task-relevant information and stability in performance. Thus, when demands on cognitive control were high (i.e., during the switches), the additional load on working memory may have led to general detrimental performance effects (cf. the general beneficial effect of greater working memory capacity across switch conditions, Tharp & Pickering, 2011). However, during pre-switch trials, greater increases in activated positive affect were associated with reduced distractor compatibility effects, suggesting that increases in positive mood high in appetitive motivation resulted in enhanced inhibition of distractors. It was speculatively suggested that this may have been observed only during pre-switch trials (cf. switch trials) as there were lower demands upon cognitive control.

The influence of positive mood on stability in cognitive control was further investigated in Study 5. In line with the effects of positive mood low in appetitive motivation on the set-shifting paradigm in Study 4 (i.e., trend towards greater flexibility), there was some evidence that positive mood low in appetitive motivation also resulted in reduced stability in cognitive control on the AX-CPT (i.e., reduced error rate on AY trials only). Therefore, this is in line with motivational intensity model of positive affect (Gable & Harmon-Jones, 2010). Furthermore, as was also the case in Study 4, a differential effect was observed for positive mood high in appetitive motivation. However, this was not in line with the directional predictions of the motivational intensity model, as rather than resulting in greater stability (i.e., faster RTs across trial types, but increased error rates only on AY trials), RTs were slower and error rates were reduced across trial types. Therefore, this suggests that this mood induction may have resulted in participants prioritising accuracy over speed when responding (i.e., reflecting a lower response threshold).

Together, these findings suggest that there is some support for the motivational intensity model of positive affect (Gable & Harmon-Jones, 2010), when more complex cognitive processes are examined. This is based on findings of enhanced divergent thinking as a result of the low appetitive positive mood induction in Study 2, which also found attenuated divergent thinking as a result of the high appetitive positive mood induction. Therefore, these results are in line with the directional predictions of this model. There is also some support for the suggestion that positive affect low in appetitive motivation results in greater flexibility and reduced stability on cognitive tasks. This was based on findings of patterns towards reduced switch

costs on the perseveration condition, but increased switch costs on the distraction condition of the set-shifting paradigm in Study 4, and a reduced error rate on AY trials on the AX-CPT in Study 5. However, these effects seem to be weakened in comparison to studies that used affective images that were briefly presented prior to each trial to induce positive affect (e.g., Liu & Wang, 2014; Muller, Dreisbach, Goschke, et al., 2007).

In contrast, there is no clear support from Studies 4 and 5 that positive affect high in appetitive motivation results in greater stability and reduced flexibility in cognitive control tasks, in line with Liu and Wang (2014) and studies using reward incentives (e.g., Frober & Dreisbach, 2014). While there was some evidence for activated positive affect leading to more stable (reduced distraction) responding during pre-switch trials of the set-switching task (Study 4), this did not transfer to the predicted divergent pattern of performance across the two switches, but rather an overall slowing effect. A similar pattern was observed on the AX-CPT in Study 5, whereby the high appetitive mood induction appeared to induce a more global effect of reduced response threshold and cautious cognitive style (i.e., prioritising accuracy over speed). Therefore, the influence of positive mood high in appetitive motivation may have more complex effects on cognitive control in comparison to more basic perceptual performance, such as attentional scope (e.g., Gable & Harmon-Jones, 2008b).

Furthermore, the results of Study 6 also support a distinction between positive mood states that vary in motivational intensity, as only positive mood high in appetitive motivation was found to result in an increase in left frontal alpha asymmetry. It is suggested that left frontal asymmetry reflects lateralisation of the appetitive motivation system, and increased activity reflects enhanced maintenance of working memory representations that are relevant to active goals (Davidson, 1992). Davidson (1992) also suggests that left frontal asymmetry reflects increased activity in the left dorsolateral prefrontal cortex, which is supported by findings that this area is associated with enhanced maintenance of representations (e.g., Barch et al., 1997). Therefore, this offers an explanation of the physiological basis that may underlie the influence of positive mood that is high in appetitive motivation on cognition. Specifically, it may be suggested that an increase in the activity of the left dorsolateral prefrontal cortex may facilitate greater stability in cognitive control (i.e., enhanced active maintenance of goal-relevant representations) as a result of positive affect that is high in appetitive motivation.

9.2.2. The Reward-as-Motivation Hypothesis

The reward-as-motivation hypothesis proposes that performance-dependent reward incentives result in greater stability in cognitive control (Goschke & Bolte, 2014). Specifically, reward incentives are proposed to enhance motivation to engage in effortful control, optimising reward pursuit (Aston-Jones & Cohen, 2005). Therefore, in contrast to the motivational intensity model (Gable & Harmon-Jones, 2010), this hypothesis proposes that positive affect high in appetitive motivation is not sufficient for greater stability in cognitive control, as the pursuit of an active appetitive goal is required. This account also suggests that positive affect that is not dependent on task performance (i.e., unrelated to the pursuit of the active goal) results in greater flexibility in cognitive control, promoting engagement in new goals/opportunities for reward (Carver, 2003). This can be contrasted with the motivational intensity model, which proposes that it is specifically positive affect low in appetitive motivation that results in greater flexibility. Thus, the reward-as-motivation hypothesis may argue that the presentation of an appetitive stimulus that was not relevant to performance would result in greater flexibility, whilst the motivational intensity model may suggest that this stimulus would result in greater stability in cognitive control on this task.

The reward-as-motivation hypothesis (Goschke & Bolte, 2014) is supported by findings that positive images presented prior to each trial on the aforementioned set-shifting paradigm results in greater flexibility in cognitive control (Dreisbach & Goschke, 2004), whilst performance-based reward incentives result in reduced flexibility (i.e., greater stability) (Muller, Dreisbach, Goschke, et al., 2007). However, Study 3 found no effect of positive mood states that were high and low in appetitive motivation on this set-shifting paradigm. Although this is not in line with the reward-as-motivation hypothesis, null results were likely due to the methodological issues with the study design. This is supported by the fact that, when these issues were addressed in Study 4, positive affect high in appetitive motivation was demonstrated to have an effect on set-shifting performance. However, rather than resulting in greater stability in cognitive control (as traditionally defined by increased perseveration and decreased distraction switch costs in this paradigm), this was found to have a general detrimental effect on performance. Therefore, it is unclear how this relates to the reward-as-motivation hypothesis.

However, Liu and Wang (2014) found that appetitive images briefly presented to participants prior to each trial resulted in greater stability on the same set-shifting paradigm. This suggests that positive affect high in appetitive motivation can promote greater stability in cognitive

control in the absence of an active goal. Interestingly, the reward-as-motivation hypothesis suggests that reward incentives must occur in close temporal proximity to the presentation of goal-relevant contextual information to facilitate enhanced active maintenance of this information (Chiew & Braver, 2016). Therefore, it may be suggested that the elicitation of transient emotional responses high in appetitive motivation, which occur in close temporal proximity to task demands, may mimic the effects of reward incentives, resulting in the enhanced maintenance of relevant contextual information. As positive mood high in appetitive motivation was induced at a temporal distance to the set-shifting task in Study 4, this may explain why this induction did not result in greater stability in cognitive control (i.e., it did not coincide with contextual information relevant to task demands).

As outlined above, it was suggested that positive mood high in appetitive motivation may not have resulted in greater stability in cognitive control (i.e., reduced switch costs in the perseveration, but increased switch costs in the distraction condition) because it did not occur in close temporal proximity to task demands. Therefore, it could be speculated that positive mood high in appetitive motivation may perhaps still result in enhanced maintenance of contextual information. However, it could be the case that this occurs in relation to information that is relevant to goals activated by the content of the mood inductions, which may have resulted in attenuated performance on the set-shifting paradigm. Specifically, attenuated performance on this paradigm may have occurred due to an increase in working memory load (due to enhanced maintenance of information that is not relevant demands of the task), which may have reduced cognitive control more generally. This is in line with findings that a lower working memory capacity results in the same general detrimental effect to performance on this paradigm (Tharp & Pickering, 2011).

The reward-as-motivation hypothesis (Goschke & Bolte, 2014) is supported by studies demonstrating that performance-based reward incentives, offered prior to trials on the AX-CPT, result in greater stability in cognitive control. However, reduced stability (i.e., greater flexibility) on this paradigm has been demonstrated to occur when positive images are briefly presented prior to each trial (e.g., Frober & Dreisbach, 2014). However, Study 5 found that positive mood high in appetitive motivation did not result in greater stability (i.e., decreased RTs across trial types but increased error rate only on AY trials) on this paradigm. This is in line with the reward-as-motivation hypothesis, which suggests that active goal pursuit is necessary for greater stability in cognitive control. Instead, positive mood high in appetitive motivation was found to result in slower RTs and fewer errors across trial types (i.e.,

prioritisation of accuracy over speed in responding), which may reflect an increased response threshold. It could be speculated that this indicates a more focused and cautious strategy to responding, which is in line with findings of generally greater switch costs on the set-shifting paradigm in Study 4.

Study 5 also found some evidence that positive mood low in appetitive motivation resulted in a general pattern of results in line with reduced stability (i.e., greater flexibility) on the AX-CPT. This effect was weaker compared to that observed in studies using briefly presented images to induce positive affect (e.g., Dreisbach, 2006). However, it was in line with the only other study to examine the effect of a more enduring mood induction on performance (van Wouwe et al., 2011). Furthermore, Study 4 also found some evidence that positive mood low in appetitive motivation resulted in a general pattern in line with greater flexibility (i.e., reduced stability), using the set-shifting paradigm. Again, this effect was weaker compared to the effects observed in studies using briefly presented images to induce affect (Dreisbach & Goschke, 2004). These findings suggest that positive affect low in appetitive motivation results in greater flexibility and reduced stability, which is in line with the reward-as-motivation hypothesis, as this positive affect was unrelated to task performance. However, it is unclear from these studies whether this effect occurs for all types of positive affect that are unrelated to task performance or only for positive affect that is low in appetitive motivation.

The effects of positive mood low in appetitive motivation on these tasks appear to be stronger for transient emotional responses (i.e., induced using affective images). Perhaps because these are in closer temporal proximity to task demands, and/or are more intense and less diffuse, in comparison to more enduring mood states (Ekman, 1992; Frijda, 1993). However, this raises the question – why do both transient and more enduring states of positive affect low in appetitive motivation result in a similar effect on cognitive control processes, whilst divergent effects occur for transient/more enduring positive affect high in appetitive motivation? The reward-as-motivation hypothesis (Goschke & Bolte, 2014) proposes that positive affect, that is unrelated to task performance, results in greater flexibility to promote exploratory behaviour and engagement in new goals or opportunities for reward (Carver, 2003). Therefore, it may not be necessary for positive affect low in appetitive motivation to coincide with task demands to have a beneficial effect (i.e., to engage in new goals and exploratory behaviour).

In contrast, reward incentives are proposed to result in greater stability in cognitive control to promote enhanced reward pursuit, as incentives facilitate motivation to engage in the active maintenance of contextual information relevant to the currently active goal (Aston-Jones &

Cohen, 2005). Therefore, it is perhaps necessary for incentives to occur in close temporal proximity to task demands (Chiew & Braver, 2016), in order to facilitate the active maintenance of the specific task-relevant information, which allows more effective reward pursuit. Thus, while both the low appetitive positive mood induction and positive affective imagery (that is unrelated to task response) may facilitate flexibility, the fact that the high appetitive mood induction is neither temporally nor actively (i.e., associated with task performance) tied to the current goal, might mean that it does not affect performance in the same manner as task-related reward incentives. In contrast, pre-trial appetitive images may be able to mimic the effect of reward incentive, as these are tightly coupled with trial by trial task performance.

The emphasis of the nature of the association between affect and task in the reward-as-motivation hypothesis, may also provide a rationale for the effect of different methods of affect manipulation on task performance. Transient emotional responses low in appetitive motivation may be able to influence performance on cognitive control tasks requiring momentary changes in control on a trial by trial basis (i.e., attentional set-shifting). In contrast, more enduring mood states low in appetitive motivation may be more suited to influencing performance on cognitive tasks requiring more enduring "modes" of control. This is in line with Study 2, which demonstrated that positive mood low in appetitive motivation enhanced divergent thinking performance, which was found to reach statistical significance, whilst only trends towards greater flexibility were observed on cognitive control tasks in Studies 4 and 5. Therefore, it may be suggested that a more enduring mood state low in appetitive motivation could be more effective in guiding cognition across the length of the divergent thinking task. However, these enduring mood states may be less effective at promoting flexibility (i.e., reduced stability) during the set-shifting paradigm/AX-CPT, which may benefit more from transient and more intense positive affect low in appetitive motivation.

9.2.3. The Neuropsychological Theory of Positive Affect

The neuropsychological theory of positive affect (Ashby et al., 1999) suggests that positive mood results in an increase in dopamine in the mesocorticolimbic and nigrostriatal pathways, promoting broader and more flexible cognition. This was supported by Chermahini and Hommel's (2012) finding that a positive mood induction, presumably low in appetitive motivation, resulted in an increase in EBR (assumed to reflect nigrostriatal dopamine activity) and enhanced divergent thinking. However, Study 2 found that EBR increased only for the

positive mood induction high in appetitive motivation, which was in turn associated with *impaired* divergent thinking. The association between increased EBR and high appetitive positive affect was also replicated in Study 4. There is evidence that positive affect high in appetitive motivation is associated with greater mesocorticolimbic dopamine activity, whilst positive affect low in appetitive motivation is associated with separate neural substrates (Berridge & Robinson, 1998). Therefore, it might instead be suggested that an increase in EBR in the high appetitive condition may reflect an increase in dopamine activity in the mesocorticolimbic pathway.

This is in line with pharmacological studies demonstrating that drugs targeting dopamine activity primarily associated with the mesocorticolimbic pathway result in an increase in EBR (Elsworth et al., 1991). However, the neuropsychological theory of positive affect (Ashby et al., 1999) suggests that an increase in dopamine activity in the mesocorticolimbic pathway is related to enhanced divergent thinking. In contrast, the results of Study 2 could be argued to suggest that an increase in mesocorticolimbic activity has a detrimental effect on divergent thinking, as the positive mood induction high in appetitive motivation was found not only to increase EBR, but also to attenuate divergent thinking performance. This is supported further by evidence of a negative relationship between EBR and divergent thinking performance in this study across the positive and neutral mood conditions, as well as the finding that increases in EBR were related to decreases in divergent thinking in Study 1. These results appear more in line with recent neurobiological models (Durstewitz & Seamans, 2008), which propose that an increase in mesocorticolimbic dopamine activity may be beneficial for stability (i.e., decreased flexibility) in cognitive control.

However, Study 2 also found that EBR was reduced, and divergent thinking was enhanced, following the positive mood induction that was low in appetitive motivation. This is in contrast to Chermahini and Hommel's (2012) findings that a positive mood induction, which was assumed to be low in appetitive motivation, resulted in enhanced divergent thinking performance, but also an increase in EBR. The decrease in EBR, as a result of the positive mood induction low in appetitive motivation, which was observed in Study 2 also does not fit with the suggestion that changes in EBR following positive mood inductions may reflect dopamine activity in the nigrostriatal pathway (Chermahini & Hommel, 2012). Instead, the findings from Study 2 may suggest that EBR is indicative of dopamine activity in the mesocorticolimbic pathway. This is based on the proposition of an antagonistic relationship between flexibility and stability in cognitive control (Goschke, 2000), such that a decrease in

mesocorticolimbic dopamine activity (i.e., reflected by EBR) may be beneficial for stability in cognitive control (i.e., attenuated divergent thinking performance), but detrimental for flexibility (i.e., enhanced divergent thinking performance).

This antagonistic balance is suggested to be mediated by a reciprocal relationship between activity of the mesocorticolimbic and nigrostriatal dopamine pathways (Cools & D'Esposito, 2011). Specifically, increased dopamine activity in the mesocorticolimbic pathway is proposed to activate a state in the prefrontal cortex dominated by tonic activity of D1 dopamine receptor neurons (as opposed to phasic activity of D2 neurons), facilitating the stabilisation of working memory representations (Durstewitz & Seamans, 2008). However, an increase in dopamine activity in the nigrostriatal pathway is proposed to activate the D1 receptor mediated "Go Pathway" in the basal ganglia (that facilitates information entry into working memory), as well as suppress the D2 receptor mediated "NoGo Pathway", which, when activated, prevents information entry into working memory (Frank & O'Reilly, 2006). Therefore, positive affect low in appetitive motivation may increase nigrostriatal, but decrease mesocorticolimbic dopamine, facilitating flexibility (i.e., reduced stability). However, positive affect high in appetitive motivation may increase mesocorticolimbic, but decrease nigrostriatal dopamine, facilitating stability (i.e., reduced flexibility) in cognitive control.

Chermahini and Hommel (2012) also demonstrated that individual differences in EBR (i.e., at baseline in the absence of a mood induction) were related to divergent thinking performance in an inverted U-shape, which suggests that performance is optimal at medium levels of dopamine activity. EBR was again suggested to reflect nigrostriatal dopamine activity, which is supported by a recent review concluding that, when assessed at baseline, EBR does primarily reflect dopamine activity in the basal ganglia (Jongkees & Colzato, 2016). It should be noted, that this is opposed to when EBR is assessed following pharmacological manipulations, which suggests that those manipulations targeting dopamine activity primarily associated with the nigrostriatal and mesocorticolimbic pathways both increase EBR (Elsworth et al., 1991). However, there was no evidence of an inverted U-shaped relationship between EBR and divergent thinking performance when this was examined prior to inductions in Study 1 or in the neutral induction of Study 2. Instead, both studies demonstrated a negative linear relationship, such that a greater EBR was associated with attenuated divergent thinking (although this was significant only in Study 2).

Chermahini and Hommel (2012) also found that individual differences in EBR moderated divergent thinking performance following the positive mood induction. This was such that

performance was enhanced only for those with a lower baseline EBR, supporting the previously demonstrated inverted U-shaped relationship for individual differences. However, neither Study 1 or 2 found that individual differences in EBR moderated divergent thinking performance following either of the positive mood inductions, which confirms the lack of inverted U-shaped relationship observed between these variables. It may be the case that the samples in these studies were situated in the negative slope of the inverted U-shape observed by Chermahini and Hommel (2012), which is supported by findings of a higher mean EBR in Studies 1 and 2. Alternatively, it could be the case that EBR assessed at baseline is reflecting activity of the mesocorticolimbic (as opposed to the nigrostriatal) dopamine pathway. This is supported by the fact that EBR was found to increase only as a result of the positive mood induction that was high in appetitive motivation in Study 2.

Positive mood that was high in appetitive motivation was also demonstrated to result in increased EBR in Study 4, supporting the suggestion that this may reflect mesocorticolimbic dopamine activity. This study also examined EBR in relation to performance on Dreisbach and Goschke's (2004) set-shifting paradigm, for which positive affect (assumed to be low in appetitive motivation) has previously been demonstrated to result in greater flexibility in cognitive control. However, despite previous studies linking higher EBR with greater flexibility (Dreisbach et al., 2005; Muller, Dreisbach, Brocke, et al., 2007; Tharp & Pickering, 2011), there was no association between EBR and switch costs for either mood induction. In contrast, there was some indication that, during the pre-switch trials – which likely requires substantially less demands upon cognitive control (cf. switch trials), greater EBR was associated with reduced distractor compatibility effects (which was also associated with increases in activated affect). This is in line with the idea that an increase in EBR reflects greater D1 activity in the prefrontal cortex, as this would imply greater stabilisation of task-relevant working memory representations.

Together, these findings suggest that the neuropsychological theory of positive affect (Ashby et al., 1999) needs to be extended to consider the motivational intensity of positive affect. Specifically, this theory suggests that broader and more flexible cognition occurs as a result of positive mood due to increases in nigrostriatal and mesocorticolimbic dopamine activity. However, the current findings suggest that this depends on motivational intensity, as positive mood high in appetitive motivation results in narrower and more stable cognition, and only this specific type of positive mood may result in an increase in dopamine activity, presumably in the mesocorticolimbic pathway. This is in line with more recent neurobiological models of

cognitive control, which propose that activity in this area is associated with stability in cognitive control (Durstewitz & Seamans, 2008). Despite this, it is important to note that findings of the current research are tentative, as although EBR was found only to be related to positive mood that was high in appetitive motivation and more stable cognition, the implications for this in relation to the neuropsychological theory are currently speculative.

9.2.4. Left Frontal Asymmetry

The motivational system underlying appetitive motivation has been suggested to be lateralised to the left prefrontal cortex (Tomarken et al., 1992). In line with this suggestion, Study 6 found that only positive mood high in appetitive motivation resulted in greater alpha left frontal asymmetry. Therefore, this is the first study to demonstrate that the effect of positive mood on left frontal asymmetry depends on the motivational intensity of affect. Specifically, whilst previous studies have demonstrated that positive affect high in appetitive motivation results in increased left frontal asymmetry (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009), there has been no comparison with positive affect that is low in appetitive motivation. Furthermore, this is the first study to demonstrate that an increase in left frontal asymmetry is associated with an increase in activated positive affect, but not deactivated positive affect. In addition, previous studies demonstrating that positive affect high in appetitive motivation results in increased left frontal asymmetry have demonstrated this effect in relation to transient emotional responses following the brief presentation of appetitive images. Therefore, Study 6 extends these findings to apply to more enduring positive mood states.

This study also found some evidence of a positive relationship between changes in EBR and changes in left frontal asymmetry, although this did not reach statistical significance. Despite this, EBR was found to be greater during the positive mood induction high in appetitive motivation, but not the positive mood induction that was low in appetitive motivation (as presented as part of Study 4), which was also the case for left frontal asymmetry. Therefore, increases in EBR did coincide with increases in left frontal asymmetry during this study, which provides some evidence that positive mood high in appetitive motivation results in increased left frontal asymmetry, most likely due to greater dopamine activity in the mesocorticolimbic pathway (i.e., the prefrontal cortex). This is in line with previous studies demonstrating that left frontal asymmetry at rest is greater for individuals with genetic variations associated with increased dopamine in the prefrontal cortex (Wacker et al., 2013).

Furthermore, when results across Study 6 were examined for the separate indexes (i.e., F8-F7 and F4-F3) that were averaged to produce the composite index for left frontal asymmetry, these results were generally found to be more reliable for the F8-F7 (as opposed to the F4-F3) index of left frontal asymmetry. The F8-F7 index is suggested to reflect activity in the dorsolateral prefrontal cortex (rather than the activity of the more mid-lateral area of the prefrontal cortex that is associated with the F4-F3 index) (Luppino & Rizzolatti, 2000). Therefore, this is in line with Davidson's (1992) suggestion that increases in left frontal asymmetry as a result of positive mood may reflect enhanced maintenance of goal-relevant representations in the dorsolateral prefrontal cortex. This is supported by research demonstrating that this area is involved in facilitating stability in cognitive control (i.e., enhanced maintenance of goal-relevant representations) (Barch et al., 1997). Based on this, it may be suggested that positive mood high in appetitive motivation increases dopamine activity specifically in the left dorsolateral prefrontal cortex, which facilitates stability in cognitive control.

9.2.5. Summary

This research aimed to examine the moderating effect of appetitive motivation in relation to the influence of positive mood on cognition. This was based on the motivational intensity model (Gable & Harmon-Jones, 2010), which suggests that positive affect that is low in appetitive motivation results in broader and more flexible cognition, to facilitate exploratory behaviour. In contrast, positive affect that is high in appetitive motivation is proposed to result in narrower and more stable cognition, to facilitate the pursuit of appetitive goals or rewards. The findings of the current research are partially in line with the predictions of the motivational intensity model, and suggest that appetitive motivation may moderate the effect of positive mood on more complex cognitive processes, such as creativity. Specifically, this was based on findings that positive mood low in appetitive motivation resulted in enhanced divergent thinking on a creativity task, whilst positive mood high in appetitive motivation resulted in attenuated divergent thinking performance (Study 2). Therefore, this extends previous research demonstrating that positive mood results in enhanced divergent thinking (e.g., Chermahini & Hommel, 2012), to suggest that this effect depends on motivational intensity.

Furthermore, there was also some evidence that appetitive motivation may moderate the influence of positive mood on cognitive control processes. This was based on findings that positive mood low in appetitive motivation resulted in a pattern of results that was in line with greater flexibility on an attentional set-shifting task (Study 4), as well as reduced stability on

the AX-CPT (Study 5). Therefore, these results are also in line with the motivational intensity model, and suggest that previous findings demonstrating similar effects for transient emotional responses (e.g., Dreisbach, 2006; Dreisbach & Goschke, 2004) can be expanded to more enduring mood states. However, there was no evidence that positive mood high in appetitive motivation resulted in the opposite pattern of results, indicating greater stability and reduced flexibility. This is not in line with the motivational intensity model, and suggest that previous findings demonstrating these effects for transient emotional responses (Liu & Wang, 2014; Muller, Dreisbach, Goschke, et al., 2007) may not extend to more enduring positive mood states that are high in appetitive motivation.

The finding that positive mood high in appetitive motivation did not result in greater stability and reduced flexibility in cognitive control may be more in line with the reward-as-motivation hypothesis (Goschke & Bolte, 2014). This account suggests that active goal pursuit is necessary for greater stability in cognitive control, rather than only positive affect high in appetitive motivation. It was speculated that the close temporal proximity of appetitive images to task demands in previous studies (i.e., Liu & Wang, 2014) may have mimicked the effects of reward, facilitating enhanced maintenance of task-relevant contextual information. However, due to the temporal distance of mood inductions and task demands in the current research, it was suggested that enhanced maintenance of goal-relevant contextual information may not have occurred. Instead it was suggested that representations relevant to the mood induction may have been activated, increasing working memory load with no benefit to task performance. This may explain findings of a general detrimental effect on set-shifting performance (Study 4), as well as a reduced response threshold on the AX-CPT (Study 5), as a possible compensatory mechanism.

Another aim of the current research was to examine the possible neurobiological mechanisms that may underlie the influence of positive mood on cognition, using EBR as an indirect measure of dopamine activity. This was based on the neuropsychological theory of positive affect (Ashby et al., 1999), which suggested that broader and more flexible cognition as a result of positive mood was due to increases in activity in the nigrostriatal and mesocorticolimbic dopamine pathways. EBR was found to increase only after the positive mood induction high in appetitive motivation (Studies 2 and 4), which was suggested to reflect an increase in dopamine in the mesocorticolimbic pathway (Depue & Collins, 1999). In Study 2, the increase in EBR was found to coincide with attenuated divergent thinking, and there was also some evidence of trends towards negative relationships between EBR and divergent thinking (Studies 1 and 2).

Therefore, this suggests that the neuropsychological theory needs to take into account the motivational intensity of positive affect, as positive affect high in appetitive motivation may result in a decrease in mesocorticolimbic dopamine activity, which facilitates narrower/more stable cognition (attenuated divergent thinking).

Individual differences in EBR have previously been demonstrated to be related to divergent thinking performance in an inverted U-shape, which is suggested to reflect the relationship between flexibility and nigrostriatal dopamine activity (Chermahini & Hommel, 2010). Furthermore, it has also previously been demonstrated that individual differences in EBR moderate the influence of positive mood on divergent thinking (Chermahini & Hommel, 2012). However, there was no evidence of quadratic relationships in the current research, and instead a negative linear relationship was observed at baseline/in neutral mood inductions (Studies 1 and 2). In line with this linear relationship, no evidence was observed that individual differences in EBR moderated the influence of either positive mood induction on divergent thinking performance. Therefore, overall, these results suggest that EBR is negatively related to flexibility, and may likely reflect mesocorticolimbic dopamine activity in the current research. This is in line with more recent neurobiological models of cognitive control (e.g., Durstewitz & Seamans, 2008), which suggest that an increase in dopamine activity in the prefrontal cortex facilitates stability (and reduced flexibility) in cognitive control.

There was no evidence of differential relationships between switch costs for the different switch conditions (perseveration vs. distraction) on the set-shifting task (Studies 3 and 4) and EBR. This was also the case for RTs on the different cue-probe conditions (AY vs. BX trials) of the AX-CPT (Study 5). However, a trend towards a positive relationship was observed between EBR and pre-switch distractor inhibition on the set-shifting task in Study 3. This was suggested to reflect the fact that under conditions requiring less cognitive control, greater stability (i.e., greater mesocorticolimbic activity) may be beneficial for ignoring distractors. Although EBR has previously been demonstrated to moderate performance on the attentional set-shifting paradigm (e.g., Dreisbach et al., 2005), this was not demonstrated to be the case in the current research., which may be due to effects only becoming apparent following positive mood inductions. However, individual differences in EBR were found to moderate the effect of positive mood on switch costs, such that only those with a higher EBR had attenuated performance across switch conditions following the high appetitive positive induction. Therefore, this suggests a possible non-linear relationship between EBR and general stability

in this study. Despite, this, individual differences in EBR were not found to moderate the effect performance on the AX-CPT, or the effect of positive mood on the AX-CPT.

Furthermore, Study 6 found that only positive mood high in appetitive motivation resulted in an increase in left frontal asymmetry. This in line with suggestions that left frontal asymmetry reflects the lateralisation of the appetitive motivation system, and that this activity reflects enhanced active maintenance of goal-relevant representations (Davidson, 1992). It also extends previous research that has found similar effects for briefly presented appetitive images (Gable & Harmon-Jones, 2008a; Harmon-Jones & Gable, 2009) to suggest that these effects may occur for more enduring positive mood states that are low in appetitive motivation. Furthermore, there was also some evidence that increases in left frontal asymmetry as a result of positive mood inductions were associated with increases in EBR. This is in line with findings that left frontal asymmetry at rest is associated with individual differences in dopamine activity in the prefrontal cortex (Wacker, 2017). Therefore, this suggests that increases in this activity, specifically in the left prefrontal cortex, may underlie the influence of positive mood high in appetitive motivation on cognition.

9.3. Limitations

9.3.1. EBR as a Marker of Dopamine

The current research was limited by the use of EBR as physiological marker of dopamine activity. In a recent review, Jongkees and Colzato (2016) concluded that, whilst EBR provides a reliable, non-invasive, cheap, and easily accessible measure of dopamine activity, it does not allow examination of dopamine activity related to specific pathways. This is a substantial caveat to any discussion that relates to interpretation of EBR in relation to dopamine function. Furthermore, while there is evidence that baseline EBR may primarily reflect D2 dopamine activity in the basal ganglia (Groman et al., 2014), pharmacological manipulations targeting the activity of D1 neurons (primarily associated with the prefrontal cortex) and D2 neurons (primarily associated with the basal ganglia) have both been found to increase EBR (e.g., Elsworth et al., 1991). Despite this, the current research only found that positive mood high in appetitive motivation increased EBR, leading to the suggestion that this may reflect greater activity of D1 dopamine receptors in the prefrontal cortex. However, this is only speculation, as more complex neuroimaging or pharmacological methodologies are required to ascertain the specific neural activity occurring as a result of this induction.

Individual differences in EBR were not found to be related to cognitive flexibility in an inverted U-shape as has been demonstrated in previous work, or moderate the influence of a positive mood induction on divergent thinking (Chermahini & Hommel, 2012). Instead, Study 2 found that there was a negative linear relationship between EBR and flexibility in divergent thinking, and a similar trend was also observed in Study 1. Therefore, this further supports the suggestion that EBR, even at baseline, reflected D1 dopamine activity in the prefrontal cortex. This is based on the finding that flexibility in divergent thinking was also found to be decreased as a result of the positive mood induction that was high in appetitive motivation. However, the current research was also limited by sample size. It may be suggested that a failure to replicate findings of Chermahini and Hommel (2012) may be due to a lack of statistical power to detect a quadratic relationship, especially in Study 2. However, it is important to note that this inverted U-shaped relationship has been demonstrated by Chermahini and Hommel (2010) with a similar sample size. Furthermore, a larger sample size was used in Study 1, and this relationship was still not observed. Therefore, the nature of the relationship between EBR and cognitive flexibility remains to be reliably validated.

Finally, the current research focused specifically on dopamine activity as the neurobiological mechanism underlying the influence of positive mood on cognition. However, other neurotransmitters are involved in positive mood – most notably opioid activity, in areas such as the shell of the nucleus accumbens (Berridge, 2009). An increase in opioid activity has been related to "liking" responses associated with the consummatory stage of appetitive behaviour and positive affect that is low in appetitive motivation (Depue & Collins, 1999). For example, the administration of opioid agonists has been found to increase self-reported drug "liking" (Lamb et al., 1991), "liking" ratings of attractive faces (Chelnokova et al., 2014), and the self-reported pleasantness of sucrose solutions (Eikemo et al., 2016). Furthermore, Schweiger et al. (2013) have also demonstrated that an opioid antagonist reversed an increase in affective "liking" responses (assessed using adjectives, such as "comfortable" and "secure") that occurred following a positive mood induction. Therefore, other neurotransmitters almost certainly play a role in the influence of positive mood on cognitive control.

9.3.2. Statistical Power

A small size may have limited statistical power in the current research, such that power may have been too low to produce significant results for some analyses due to Type II error (Wilson Van Voorhis & Morgan, 2007). For each study, sample size was based on previous studies

conducted in this area, and cell size for ANOVAs examining the influence of positive mood inductions was largely in line with rules of thumb for this type of analysis (i.e., approximately 30 participants) (J. Cohen, 1988). Therefore, it is unlikely that any non-significant effects of the positive mood inductions on the cognitive tasks used in the present research are due to low statistical power. Despite this, a small sample size may have been problematic for examining differences in the influence of positive mood inductions on cognitive tasks for those with high compared to low EBR. This is because ANOVAs for this analysis often had small cell sizes and in some cases approached the recommended minimum of seven participants (J. Cohen, 1988). Thus, this may have prevented significant results from being observed.

Small sample size may have also been especially problematic for examining the relationships between baseline EBR and performance on cognitive tasks. Liner regression analysis requires a larger sample size than when using ANOVA (J. Cohen, Cohen, West, & Aiken, 2003), with rules of thumb suggesting approximately 100 participants, although this may depend on the number of predictors (Green, 1991; Van de Leeden, Busing, & Meijer, 1991). Previous research suggests that the relationships between dopamine activity and performance of cognitive tasks may follow an inverted U-shaped relationship (Cools & D'Esposito, 2011), which has demonstrated to be the case for the relationship between EBR and divergent thinking task performance (Chermahini & Hommel, 2012). As non-linear regression requires a particularly large sample size (Peddada & Haseman, 2005), it may be the case that studies in the current research do not have sufficient statistical power to produce significant inverted U-shaped relationships for this analysis.

Although low sample size may have been a limitation of the current research, in terms of reducing the probability of significant effects being determined in some analyses, it does not prevent the observation of general non-significant patterns in results being observed, which can be investigated further in future research with large sample sizes. Interestingly, sample sizes used for regression analyses in the current research were in line with previous studies demonstrating inverted U-shaped relationships between EBR and divergent thinking (Chermahini & Hommel, 2012). Therefore, despite the potentially low statistical power of these analyses due to small sample sizes (e.g., $N = 30$ for this analysis in Study 2), these findings still demonstrate that the previously demonstrated non-linear relationship between EBR and divergent thinking may not be as reliable as is suggested in previous studies. Furthermore, a non-linear relationship between EBR and divergent thinking was also not found in Study 1,

which had a larger sample size (N = 64 for this analysis), supporting the lack of reliability for this relationship.

9.3.3. Individual Differences

One broad limitation of the current research is that it does not take into account individual differences that may be related to appetitive motivation. A behavioural activation system (e.g., Gray & McNaughton, 2000) or behavioural facilitation system (Depue & Collins, 1999) is proposed to mediate appetitive motivation, generating positive affect high in appetitive motivation, and facilitating approach behaviour towards appetitive stimuli. Individual differences in behavioural activation/facilitation has been suggested to underlie the personality trait of extraversion (Smillie, 2013), which is associated with achievement, dominance, sociability, and positive emotionality (DeYoung, 2013). Individual differences in both behavioural activation and extraversion have been found to predict the experience of greater positive affect during mood inductions that are high in appetitive motivation (Smillie et al., 2012), and extraversion has been found to moderate the influence of positive mood inductions on tasks assessing creativity (Stafford et al., 2010). Therefore, these individual differences may have moderated the effectiveness of appetitive mood inductions in the current research, as well as subsequent performance on cognitive tasks.

Other personality traits have been found to have a more direct influence on cognition. For example, psychoticism is a personality trait that is associated with impulsivity (Diaz & Pickering, 1993), and antisocial emotional expression (Eysenck, 1992). It has been suggested that psychoticism may be related to reduced flexibility in cognitive control (Smillie, Cooper, Tharp, & Pelling, 2008). In line with this suggestion, Tharp and Pickering (2011) found that psychoticism moderated performance on Dreisbach and Goschke's (2004) attentional set-shifting paradigm. This was such that those individuals who scored higher for psychoticism demonstrated reduced flexibility (i.e., switch costs were increased in the perseveration condition, but decreased in the distraction condition), whilst those who scored lower for psychoticism demonstrated greater flexibility (i.e., switch costs were decreased in the perseveration condition, but increased in the distraction condition). Therefore, individual differences in psychoticism may have moderated performance on cognitive tasks in the current research.

Tharp and Pickering (2011) also demonstrated that individual differences in working memory capacity moderated performance on Dreisbach and Goschke's (2004) set-shifting paradigm.

This was such that a greater working memory capacity was generally beneficial to performance (i.e., switch costs were reduced across both the perseveration and distraction condition for those with a greater working memory capacity), which was speculated to reflect facilitated updating of target colours following the switch. Working memory capacity has also been demonstrated to moderate performance on the AX-CPT, such that those individuals with a higher working memory capacity display greater stability in cognitive control (i.e., slower RTs on AY trials, for which active maintenance of contextual information is detrimental to performance) (Richmond, Redick, & Braver, 2015). However, participants with a lower working memory capacity displayed reduced stability in cognitive control (i.e., less errors on AY trials) (Redick, 2014). Therefore, individual differences in working memory capacity may also have influenced performance on cognitive tasks in the current research.

The studies outlined above suggest that performance on the cognitive tasks in the current research may be moderated by individual differences in personality (e.g., extraversion and psychoticism), as well as those relating to cognitive abilities, such as working memory capacity. However, it is unlikely that these factors influenced results in the current research, as participants were randomly assigned to mood conditions. Therefore, this was unlikely to have any meaningful impact on results relating to performance on cognitive tasks or other analyses. Furthermore, with the exception of Studies 3 and 5, all studies in the current research used within-subject designs for comparing the effects of positive mood inductions on cognition (i.e., as well as the effectiveness of the mood inductions, and the effects of these on EBR, etc.). Therefore, the inclusion of neutral mood inductions (or a baseline assessment in Study 1) takes into account any individual differences that may have influenced results.

9.3.4. Affect and Motivation

A further broad limitation of the current research is the focus on positive mood that varies in motivational intensity, as it is suggested that not all states that are high in appetitive motivation are of a positive valence. The most notable example of this is anger, as this is suggested to activate a behavioural activation system (Harmon-Jones, 2003), which is contrary to the widely accepted view that this system elicits positive affect (i.e., Gray & McNaughton, 2000). It is argued that anger is associated with approach behaviour, in terms of promoting aggression and attack, often in the absence of motivation related to defence (Harmon-Jones & Sigelman, 2001). This is supported by evidence of positive correlations between individual differences in behavioural activation and the propensity to experience aggression (Harmon-Jones et al.,

2002). Furthermore, there is also evidence that anger may result in narrower and more stable cognition, such as a narrower attentional scope (Finucane, 2011), and less diverse cognitive categorisation, when participants are asked to rate the fit between categories and examplers (Gable, Poole, & Harmon-Jones, 2015).

Secondly, the focus of the current research was limited to appetitive motivation. However, goal-directed behaviour is also suggested to be mediated by a "withdrawal" or "avoidance system". This is suggested to be responsive to aversive stimuli, facilitating avoidance or escape behaviour (Gray & McNaughton, 2000). Negative affective states that are high vs. low in motivational intensity (e.g., fear or disgust vs. sadness) are suggested to have similar differential effects on cognition as has been described for positive affective states that are high vs. low in appetitive motivation (Gable & Harmon-Jones, 2010). Specifically, broader/more flexible cognition during negative affect low in motivational intensity is proposed to facilitate disengagement from goals that have been terminally blocked (i.e., are unable to be achieved) (Thompson, Woodward, & Stanton, 2011). In contrast, narrower/more stable cognition for negative affect high in motivational intensity is suggested to facilitate focus on avoiding or escaping aversive stimuli. This is supported by the finding that affective images inducing sadness result in a broader attentional scope, whilst images inducing disgust result in narrower attentional scope (Harmon-Jones, Gable, & Price, 2012).

9.4. Applied Implications

9.4.1. Affective Disorders

Although the primary impact of the present research relates to the development of theory, the longer-term implications of the research may have broad practical importance, such as in relation to affective disorders. For example, depression has been demonstrated to result in cognitive impairments, such as deficits in problem-solving, planning, decision-making, memory, and concentration (Hammar & Ardal, 2009). This has led to the suggestion that cognitive control may be impaired in depression, and this is argued to be specifically related to deficits in cognitive flexibility. This is based on studies that have consistently demonstrated that performance is attenuated on tasks that require flexibility in cognitive control (for a review see Veiel, 1997), such as when it is necessary to switch attention between different categories of stimuli to make appropriate responses (F. C. Murphy, Michael, & Sahakian, 2012). This is in line with the proposition that depression is associated with an inability to disengage from a negative affective state (Holtzheimer & Mayberg, 2011). The findings from the current

research suggest that the reduced experience of positive affect, specifically that which is low in appetitive motivation, may contribute to these impairments in cognitive flexibility observed in patients with depression.

This has important implications for the treatment of these disorders, as current interventions focus on reducing the experience of negative affect in depression. For example, cognitive behavioural therapy is one common intervention, which targets negative dysfunctional thoughts (Hofmann, 2011). This has generally been demonstrated to be effective in reducing symptoms of depression (Johnsen & Friborg, 2015). However, whilst cognitive behavioural therapy has been found to be effective in reducing the experience of negative affect, levels of positive affect have still been found to be below community norms following treatment (Dunn, German, Hollon, & ReRubeis, 2016). Therefore, it has been suggested that interventions should also target the upregulation of positive affect (Dunn, 2012). This is supported by the finding that a new intervention focusing on positive thoughts, emotions, and behaviour (e.g., gratitude, acts of kindness, and optimism) was effective in increasing the experience of positive affect in a sample of patients with depression (Taylor, Lyubomirsky, & Stein, 2017). Furthermore, this intervention was also found to significantly reduce negative affect, in line with establish measures, such as cognitive behavioural therapy.

However, depression is also associated with deficits in appetitive motivation, such that patients are less sensitive to appetitive stimuli compared to healthy populations (Henriques & Davidson, 2000). It has been suggested that this may be due to reduced levels of dopamine activity (Keedwell, Andrew, Williams, Brammer, & Phillips, 2005). The current research suggests that this may be specifically related to lower levels of dopamine in the mesocorticolimbic pathway, as only positive affect high in appetitive motivation was found to result in an increase in EBR. Specifically, a decrease of appetitive motivation in depression may be suggested to have a detrimental effect on the maintenance of goal-relevant representations in working memory. This is in line with findings that patients have reduced left frontal asymmetry compared to healthy populations (e.g., Shankman, Klein, Tenke, & Bruder, 2007), as this has been suggested to reflect this process (Davidson, 1992). However, current pharmacological treatment options for depression focus on other neural substrates (Cowen & Browning, 2015), but the findings of the current research are in line with suggestions that treatments may be improved by also targeting dopamine activity (Hori & Kunugi, 2012).

9.4.2. Life Outcomes

The findings of the current research are also relevant to the association between the experience of favourable life outcomes in healthy populations. For example, there is a positive correlation between the experience of positive affect and physical health (Lyubomirsky et al., 2006), mental health (Koivumaa-Honkanen et al., 2001), the number of social relationships (G. R. Lee & Ishii-Kuntz, 1987), and success at work (Wright & Cropanzano, 2000). The current findings are in line with the broaden-and-build theory, which suggests that this association exists because positive affect promotes broader and more flexible cognition, facilitating engagement in novel and exploratory behaviours (Fredrickson, 1998). It is proposed that this behaviour enables the individual to build upon their personal resources (e.g., visiting the gym, making a new friend, or reading a book), which promotes more favourable life outcomes. Fredrickson and Branigan (2001) suggested that broader and more flexible cognition occurs for a range of positive emotions, including joy, interest, contentment, pride, and love. However, the findings of the current research suggest that this effect may more accurately be described to occur as a result of positive affect low in appetitive motivation.

Therefore, encouraging individuals to take part in activities to increase their experience of positive affect low in appetitive motivation may promote more favourable life outcomes. There is evidence that engaging in activities to increase the experience of positive affect can increase life satisfaction. This includes writing letters of gratitude (Boehm, Lyubomirsky, & Sheldon, 2011), counting one's blessings (Emmons & McCullough, 2003), performing acts of kindness (Layous, Lee, Choi, & Lyubomirsky, 2013), using one's strengths in new ways (Seligman, Steen, Park, & Peterson, 2005), affirming one's important values (S. K. Nelson, Fuller, Choi, & Lyubomirsky, 2014), and meditating on positive feelings towards self and others (Fredrickson, Cohn, Coffey, Pek, & Finkel, 2008). It is suggested that taking part in these activities increases the experience of positive emotions, which in turn leads to increases in personal resources (e.g., physical and mental health, social relationships, psychological and intellectual skills, etc.), and thus more favourable life outcomes (Lyubomirsky & Layous, 2013).

9.5. Future Directions

9.5.1. Creativity

Further investigation of the moderating role of appetitive motivation in relation to the influence of positive mood on convergent thinking is required. Although Study 1 found no effect of positive mood high and low in appetitive motivation on divergent and convergent thinking, this was suggested to be due to the mood inductions being ineffective in this study. However, there was evidence of similar relationships between positive affect (as well as EBR) and performance on divergent and convergent thinking tasks. This was unexpected, as positive mood high and low in appetitive motivation were hypothesised to have different effects on divergent and convergent thinking. This was based on the assumption that divergent thinking requires broader and more flexible cognition to produce many diverse ideas, whilst convergent thinking requires narrower and more stable cognition to derive the ultimate solution to a problem. Therefore, differential relationships would be expected between activated positive affect (increased for high appetitive positive mood) and deactivated positive affect (increased for low appetitive positive mood) and the two types of creativity.

The finding of negative relationships between activated positive affect and divergent thinking in Study 1 were replicated in Study 2, and there was also a positive relationship between deactivated positive affect and divergent thinking. Therefore, this is in line with expectations, as well as additional findings, demonstrating that divergent thinking was attenuated for the high appetitive induction, but enhanced for the low appetitive induction. However, Study 1 also found that activated positive affect and convergent thinking were negatively correlated. As stated above, this is not in line with expectations of a differential effect between divergent and convergent thinking. Therefore, it could be suggested that, in Study 1, the consistent relationships between these two types of creativity may be because the Remote Associates Test requires a component of divergent thinking (C. S. Lee et al., 2014). Although, only a weak correlation was found between this and performance on the Alternate Uses Task in Study 1, which is in line with previous work (e.g., Taft & Rossiter, 1966).

Therefore, the effect of positive mood on convergent thinking still remains unclear, especially in relation to the moderating role of appetitive motivation. Interestingly, previously studies have demonstrated that positive mood inductions enhanced performance on the Remote Associates Test, suggesting enhanced convergent thinking (e.g. Isen et al., 1987). However, these studies have often used mood inductions that involved presenting participants with gifts, such as sweets and chocolates. Given the appetitive nature of these stimuli, this could have induced positive mood that is high in appetitive motivation. Thus, results would be in line with

the suggestion that this type of positive mood promotes narrower and more stable cognition (i.e., is beneficial for convergent thinking). Therefore, further research should be conducted to examine the differential influence of positive mood states high and low in appetitive motivation on the Remote Associates Test. This research should use a similar design to Study 2, as mood inductions were demonstrated to be effective in this study. Specifically, participants could complete neutral and positive (either high or low appetitive) in separate experimental sessions, followed by the Remote Associates Test.

It may also be interesting to conduct further research to examine the influence of positive mood on measures of convergent thinking other than the Remote Associates Test. For example, intelligence tests, such as Raven's Advanced Progressive Matrices, which has previously been demonstrated to have a moderate positive correlation with the Remote Associates Test (e.g., Chermahini & Hommel, 2010). Interestingly, a recent study conducted by Yamada and Nagai (2015) compared the influence of a positive mood induction on divergent and convergent thinking. Participants listened to music and thought about happy events to induce positive mood, which was found to result in an increase in deactivated positive affect. This was found to enhance only divergent thinking and have no effect on convergent thinking, in line with the expectations for the low appetitive positive mood induction in Study 1. However, this study did not take into account the motivational intensity of positive affect, and thus the differential effect of positive mood that is high and low in appetitive motivation on convergent thinking still remains unclear at present.

9.5.2. Cognitive Control

The results of Studies 4 and 5 found some evidence that positive mood low in appetitive motivation may result in greater flexibility on Dreisbach and Goschke's (2004) attentional set-shifting task, as well as reduced stability on the AX-CPT. However, the effects of the low appetitive positive mood induction on the set-shifting task did not approach significance and appeared only as a general pattern, whilst the same pattern of results reached significance in previous studies using positive images presented prior to each trial to induce affect (e.g., Liu & Wang, 2014). Previous studies have also demonstrated that pre-trial positive images reduced stability on the AX-CPT, in terms of differential effects on AY vs. BX trials (e.g., Dreisbach, 2006). However, Study 5 found that the positive mood induction low in appetitive motivation resulted in reduced stability only on AY trials. This was also the case for van Wouwe et al. (2011) study, which also used a positive mood induction to induce affect. Therefore, enduring

positive mood states and transient emotional responses that are low in appetitive motivation may have a similar, but weaker, effects on the balance between flexibility and stability in cognitive control.

In contrast, Study 4 and Study 5 suggest that more enduring mood states and transient emotional responses high in appetitive motivation may have different effects on the balance between flexibility and stability in cognitive control. Study 4 demonstrated that positive mood high in appetitive motivation had a general detrimental effect on the set-shifting paradigm, rather than reduced flexibility as previously demonstrated in studies using reward cues prior to trials (e.g., Muller, Dreisbach, Goschke, et al., 2007). Therefore, it was speculated that both transient and enduring affective states may facilitate stability in cognitive control. However, as transient emotional responses occur in close temporal proximity to task demands, this may facilitate the maintenance of information that is relevant to task performance, whilst, due to temporal distance from demands, more enduring mood states may not. This may also explain findings of a reduced response threshold (i.e., prioritisation of speed over accuracy) across trial types on the AX-CPT in Study 5, which may reflect a strategy to overcome an increased working memory load as a result of the high appetitive positive mood induction.

Therefore, future research should focus on comparing the differential effect of enduring and more transient emotional responses on Dreisbach and Goschke's (2004) set-shifting paradigm, as well as on the AX-CPT. This may involve directly comparing the effects of affective images (inducing transient emotional responses) to positive mood inductions (inducing more enduring mood states) on these tasks. It is suggested that for each paradigm, two separate experiments should be conducted for positive affect high and low in appetitive motivation, so that each experiment has four affective conditions: i) pre-trial neutral images; ii) pre-trial positive images; iii) neutral mood induction; iv) positive mood induction. One experiment would allow the direct comparison of transient emotional responses and more enduring mood states for positive affect high in appetitive motivation (relative to neutral affect), and the other would allow the same comparison, but for positive affect low in appetitive motivation. Transient emotional responses could be induced using stimuli from Liu and Wang's (2014) study, which demonstrated differential effects on the set-shifting task, and more enduring mood states could be induced using stimuli from the current research.

Although the effect of pre-trial images high in appetitive motivation on Dreisbach and Goschke's (2004) set-shifting paradigm has been examined by Liu and Wang (2014), the effect of these images has not previously been examined on the AX-CPT. However, previous research

has examined the influence of cues indicating that a monetary reward is available, based on performance, prior to each trial. Across a number of studies, it has consistently been demonstrated that these reward cues resulted in faster RTs across trial types, but only reduced error rate on AY trials, which is the only trial type that benefits for greater stability (Chiew & Braver, 2013; Frober & Dreisbach, 2014; Locke & Braver, 2008). Therefore, it would be interesting to compare the effects of performance-dependent reward cues to briefly presented appetitive images on the AX-CPT. Appetitive images may have a similar effect to reward-cues (i.e., resulting in faster RTs across trials, but reduced error rate only AY trials). However, faster RTs across trial types could be the result of a strategy employed to increase the chance of performance-dependant rewards. Therefore, it could be the case that RTs may not increase across trial types as a result of appetitive images, and instead performance may be attenuated on the BX trials.

9.5.3. Left Frontal Asymmetry

Study 6 found that only positive mood high in appetitive motivation resulted in greater left frontal alpha asymmetry. This induction was also found to result in greater EBR, suggesting that mesocorticolimbic dopamine activity may contribute to left frontal asymmetry. Therefore, it may be suggested that an increase in left frontal asymmetry may reflect greater stability (or reduced flexibility) in cognitive control. This is in line with previous theories that have proposed that left frontal asymmetry may reflect enhanced active maintenance of goal-relevant representations (e.g., Davidson, 1992). Support for this proposition comes from studies conducted by Gable and Harmon-Jones, which demonstrate that transient emotional responses to appetitive stimuli result in an increase in left frontal asymmetry, as well as a narrower attentional scope (Harmon-Jones & Gable, 2009; Gable & Harmon-Jones, 2008). However, these studies examined left frontal asymmetry in the short period between trials (12 seconds), and left frontal asymmetry has not been examined in relation to the effect of more enduring positive mood states on attentional scope.

Left frontal asymmetry has also not been examined in relation to the balance between flexibility and stability in cognitive control (i.e., performance on Dreisbach and Goschke's set-shifting task or the AX-CPT), or the effect of positive mood on cognitive control. Although one study conducted by Wacker (2017) did attempted to examine the influence of positive mood states that were high and low in appetitive motivation on left frontal asymmetry in relation to AX-CPT performance, these mood inductions were not found to result in the expected changes to

positive affect. Therefore, future studies should replicate this work using a more effective induction procedure, such as those used in the current research. EEG recordings for Study 6 and performance on the set-shifting task for Study 4 were collected as part of the same experiment (although presented separately). However, reduced flexibility on this task was not observed following the high appetitive positive mood induction, and there were no significant effects or associations for left frontal asymmetry and set-shifting performance. Thus, future research should focus on the AX-CPT and left frontal asymmetry.

Furthermore, Study 2 found that only the positive mood induction low in appetitive motivation resulted in enhanced divergent thinking, whilst this was attenuated for the positive mood induction high in appetitive motivation. This, in combination with the finding that left frontal asymmetry was enhanced during the positive mood induction high in appetitive motivation in Study 6, suggests that greater left frontal asymmetry may be associated with attenuated divergent thinking. This is in line with a review of studies using a variety of methods to assess hemispheric asymmetry (including EEG, PET, fMRI, and lateral saccades), which concluded that increased activity in the right hemisphere was associated with creativity, and particularly divergent thinking (Mihov, Denzler, & Förster, 2010). However, there is no research to date linking the influence of positive mood on divergent thinking to left frontal asymmetry. Furthermore, as the focus of research examining the effect of left frontal asymmetry on creativity has focused on divergent thinking, research is still needed to ascertain the effects on convergent thinking.

9.5.4. Spontaneous Eye Blink Rate

There was little evidence of an inverted U-shaped relationship between EBR and cognition when assessed at baseline (Study 1) or during neutral inductions (Study 2, 4, and 5). Instead, Study 1 and Study 2 found evidence of a negative linear relationship between divergent thinking and EBR, suggesting that greater dopamine activity was associated with narrower and more stable cognition. Whilst the other studies (Study 4 and 5) found no evidence that EBR was related to the balance between flexibility and stability on Dreisbach and Goschke's (2004) set-shifting task or the AX-CPT. Therefore, these findings are not in line with suggestions of an inverted U-shaped relationship between baseline EBR and flexibility (Jongkees & Colzato, 2016), or previous studies demonstrating a non-linear relationship between EBR and divergent thinking (Chermahini & Hommel, 2010, 2012). Thus, more research is needed to establish the relationship between baseline EBR and cognition, especially for divergent thinking, as it is

unclear why a negative linear relationship was found between these variables, rather than the inverted U-shaped relationship reported in previous work.

Jongkees and Colzato (2016) suggest that there may be important methodological variables that impact EBR measurement. For example, Doughty (2001) demonstrated that tasks being completed by participants may impact EBR, as EBR was found to be reduced by reading, but increased when conversing. In addition, mental workload and task difficulty have also previously been found to reduce EBR (Lean & Shan, 2012). Other studies examining EBR have conducted interviews or asked participants to watch videos during EBR recording, which Jongkees and Colzato (2016) suggest may confound EBR measurement. It is suggested that to provide a reliable measurement of EBR, this should be assessed during 'primary gaze', when participants are in silent rest and looking straight ahead. Whilst Chermahini and Hommel (2010, 2012) recorded EBR during similar conditions to assess primary gaze, the present research asked participants to engage in mental imagery and listen to music during this period. Therefore, future research should ascertain whether the non-linear relationship between baseline EBR and cognitive flexibility can be established (and replicate Chermahini and Hommel's findings) when primary gaze is assessed.

As discussed in the previous section, the sample size for non-linear regression was small in the present work, especially in Study 2, where a negative linear relationship between EBR in the neutral induction and divergent thinking was observed. As the mean EBR in this study was higher compared to those in samples from Chermahini and Hommel's (2010, 2012) studies, it could be the case that this may reflect the negative curve of an inverted U-shape. This explanation may seem unlikely for several reasons (see Section 9.5.1), but in order for this to be determined with validity more research needs to be conducted. Therefore, further research should be conducted with larger sample sizes to examine the relationship between baseline EBR and divergent thinking. This research should take into account the methodological considerations outlined above (i.e., EBR recording during primary gaze). It should also take into account other factors that have been suggested to influence EBR, such as time of day (Barbato et al., 2000) and smoking behaviour (Evinger et al., 1993). These may both have been factors that could have influenced EBR in the present research.

Chermahini and Hommel (2012) suggested that EBR reflects dopamine activity in the nigrostriatal pathway. Thus, an inverted U-shaped relationship between EBR and divergent thinking supports the suggestion that greater flexibility in cognitive control is related to an increase in dopamine activity in the basal ganglia (Frank & O'Reilly, 2006). However, an

alternative explanation for the lack of inverted U-shaped relationship between EBR and divergent thinking in Study 2 may be that EBR reflects mesocorticolimbic rather than nigrostriatal dopamine activity. This would be in line with suggestions that increases in dopamine activity in the prefrontal cortex result in greater stability in cognitive control (Durstewitz & Seamans, 2008). Further support comes from findings from Study 4, which demonstrated that a greater EBR was related to reduced distractor compatibility effects (i.e., increased inhibition of pre-trial distractors) on the set-shifting task. This is in line with the idea that EBR is related to enhanced maintenance of representations (i.e., greater dopamine activity in the prefrontal cortex) in the current research.

Further evidence supporting the suggestion that EBR may reflect dopamine activity in the mesocorticolimbic pathway in the current research comes from the finding that only positive mood high in appetitive motivation resulted in increased EBR in Study 2 and Study 4, as well as findings that EBR was positively correlated with activated (but not deactivated positive affect). This is based on previous research suggesting that positive mood high in appetitive motivation is characterised by highly activated positive affect, and is associated with the activity of the mesocorticolimbic dopamine system (Depue & Collins, 1999). However, the particular areas of the brain and specific dopamine pathways reflected by EBR can only be speculated using this index of activity. Future research should focus on elucidating the neural and physiological mechanisms underlying EBR, especially in relation to mood and cognition. Combining methodologies, such as functional imaging measures (e.g., fMRI and PET) and pharmacological manipulations, with physiological and behavioural measures may be particularly useful in this endeavour.

9.6. Conclusions

The current research found some evidence that appetitive motivation moderated the influence of positive mood on creativity. This was in line with the motivational intensity model (Gable & Harmon-Jones, 2010), such that positive mood low in appetitive motivation resulted in enhanced divergent thinking, whilst divergent thinking was attenuated for positive mood high in appetitive motivation. There was also some evidence that positive mood low in appetitive motivation had effects on more fundamental and basic cognitive processes, which were in line with the directional predictions of the motivational intensity model. This was such that positive mood low in appetitive motivation resulted in greater flexibility and reduced stability in cognitive control. However, positive mood high in appetitive motivation was not found to result

in the expected effects (i.e., greater stability and reduced flexibility), leading to the suggestion that this may only occur when positive affect high in appetitive motivation is elicited in close temporal proximity to the task demands, as this facilitates the enhanced active maintenance of contextual information relevant to the task. This would account for Liu and Wang's (2014) finding of reduced stability (i.e., greater flexibility) following the brief presentation of appetitive images prior to each trial on a set-shifting paradigm.

EBR was found to increase only following positive mood inductions that were high in appetitive motivation, which was suggested to reflect greater mesocorticolimbic dopamine activity (Depue & Collins, 1999). There was also no evidence of the previously demonstrated inverted U-shaped relationship between individual differences in EBR and divergent thinking (Chermahini & Hommel, 2010). Instead, EBR was found to be negatively related to divergent thinking, suggesting that an increase in mesocorticolimbic dopamine activity may facilitate narrower and more stable cognition, which is contrary to the predictions of the neuropsychological theory of positive affect (Ashby et al., 1999). Furthermore, EBR was not found to be differentially related to flexibility and stability in cognitive control, as has been demonstrated in previous studies (Dreisbach et al., 2005), or to moderate the influence of positive mood states on these processes. Left frontal asymmetry was found to be increased following only a positive mood induction high in appetitive motivation, and there was some evidence that increases in EBR were associated with increases in left frontal asymmetry. This suggests that positive mood high in appetitive motivation may result in narrower/more stable cognition due to an increase in dopamine activity in the mesocorticolimbic pathway, specifically in the left dorsolateral prefrontal cortex.

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