Acta Psychologica 218 (2021) 103357

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Experimental control of conflict in a predictive visual probe task: Highly reliable bias scores related to anxiety

Thomas Edward Gladwin[a,b,c,*], Monika Halls[c], Matthijs Vink[d]

[a] Behavioural Science Institute, Radboud University Nijmegen, Nijmegen, the Netherlands
[b] Institute of Lifecourse Development, University of Greenwich, London, United Kingdom
[c] University of Chichester, Chichester, United Kingdom
[d] Departments of Developmental and Experimental Psychology, Utrecht University, Utrecht, the Netherlands

ARTICLE INFO

Keywords:
Anticipation
Attention
Predictive
Reliability
Anxiety

ABSTRACT

Concerns have been raised about the low reliability of measurements of spatial attentional bias via RT differences in dot-probe tasks. The anticipatory form of the bias, directed towards predicted future stimuli, appears to have relatively good reliability, reaching around 0.70. However, studies thus far have not attempted to experimentally control task-related influence on bias, which could further improve reliability. Evoking top-down versus bottom-up conflict may furthermore reveal associations with individual differences related to mental health. In the current study, a sample of 143 participants performed a predictive Visual Probe Task (predVPT) with angry and neutral face stimuli online. In this task, an automatic bias is induced via visually neutral cues that predict the location of an upcoming angry face. A task-relevant bias was induced via blockwise shifts in the likely location of target stimuli. The bias score resulting from these factors was calculated as RTs to target stimuli at locations of predicted but not actually presented angry versus neutral faces. Correlations were tested with anxiety, depression, self-esteem and aggression scales. An overall bias towards threat was found with a split-half reliability of 0.90, and 0.89 after outlier removal. Avoidance of threat in blocks with a task-relevant bias away from threat was correlated with anxiety, with correction for multiple testing. The same relationship was nominally significant for depression and low self-esteem. In conclusion, we showed high reliability of spatial attentional bias that was related to anxiety.

1. Introduction

When confronted with multiple stimuli that could evoke a response, but to which only some can be responded at a time, selective attention is required to select particular stimuli for further processing (Carrasco, 2011). This kind of attention can be modelled in computational terms using saliency maps (Soltani & Koch, 2010; Treue, 2003). Salience is determined by interactions between endogenous attention, i.e., voluntary, controlled, goal-dependent “top-down” attentional processes, and exogenous attention, i.e., reflexive, automatic, stimulus-driven “bottom-up” attentional processes (Corbetta & Shulman, 2002; Posner, 1980; Schneider & Shiffrin, 1977; Treisman & Gelade, 1980; Van der Stigchel et al., 2009). Importantly, automatic influences on attention have been expanded from basic visual stimulus features to include emotional or motivational features (Cisler & Koster, 2010; Niu et al., 2012). For example, stimuli with high relevance for survival such as snakes or spiders attract visual attention more than neutral stimuli such as flowers or mushrooms (Mogg & Bradley, 2006; Öhman et al., 2001; Rinck & Becker, 2006); positive stimuli also attract visual attention more than neutral stimuli, although possibly to a lesser extent than negative stimuli (Stefanics et al., 2012). Emotion-related biases in spatial attention allocation are commonly assessed by the dot-probe task (MacLeod et al., 1986; Mogg & Bradley, 1999). The dot-probe task is a two-choice decision task in which spatial attention is hypothesized to be automatically shifted by pairs of salient and neutral task-irrelevant probes that alter the reaction time to task-relevant stimuli. Probe stimuli are presented at the locations of either the salient or the neutral cue stimuli. The reaction time difference between the probe-on-salient trials and probe-on-neutral trials provides a quantification of attentional bias towards or away from the salient cue stimuli. Attentional bias towards or away from salient cues have been linked to an array of mental health problems (Cisler & Koster, 2010; Dalgleish et al., 2010). For example, bias towards threat is

* Corresponding author at: Behavioural Science Institute, Radboud University Nijmegen, Nijmegen, the Netherlands.
E-mail address: thomas.gladwin@ru.nl (T.E. Gladwin).

https://doi.org/10.1016/j.actpsy.2021.103357
Received 1 July 2020; Received in revised form 4 May 2021; Accepted 22 June 2021
Available online 24 June 2021
0001-6918/© 2021 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

associated with anxiety disorders (Bar-Haim et al., 2007; Cisler & Koster, 2010), and post-traumatic stress disorder (Naim et al., 2014), bias towards negative information is related to depression (Peckham et al., 2010), bias towards rejection predicts self-esteem vulnerabilities (Ravary & Baldwin, 2018), bias towards social threat is linked to hostile intent attribution in children (Miller & Johnston, 2019), and a bias towards aggression-related cues was observed in a sample of intimate partner aggression perpetrators with problematic alcohol use (Massa et al., 2019). Positive visual attentional bias has been shown to aid emotion regulation in stressful situations (Wadlinger & Isaacowitz, 2008). However, it is statistically necessary for the detection of relationships involving individual differences that the used measures are reliable, and recent studies have shown that the dot-probe task has very poor reliability (e.g., Ataya et al., 2012; Brown et al., 2014; Chapman et al., 2019; Cooper et al., 2011; Dear et al., 2011; Kappenman et al., 2014; Waechter & Stolz, 2015). Further, clinically anxious individuals were not found to have the expected bias towards threat in a meta-analysis of baseline measurements in studies aimed at tests of Attentional Bias Modification (Kruijt et al., 2019). It is thus uncertain which of the many interesting, sometimes complex results in the dot-probe literature reflect true effects, as it seems likely at least some proportion must involve false positives given a noisy bias measure. Results may need to be (re-)gathered using attentional bias measures with improved psychometric properties for the field to move forward.

The predictive version of the Visual Probe Task, predVPT (Gladwin, 2016; Gladwin & Vink, 2018), may aid in this endeavour; the task was originally termed the "cued" VPT, cVPT, which has previously been suggested to be changed to the conceptually clearer term used here (Gladwin & Vink, 2020). The task was originally designed to help measure attentional bias variability by removing undesirable sources of trial-to-trial variability, but this removal of noise may also improve split-half reliability. During the predVPT, pictorial and probe trials are selected at random throughout the task (Fig. 1). In the pictorial trials, two visually neutral predictive cues consistently predict the locations of subsequent salient and control stimuli (e.g., angry vs neutral facial expressions). This is intended to evoke automatic anticipatory processing that can bias spatial selective attention. The bias is assessed by the performance on probe trials. During these trials the predictor stimuli are presented but, instead of the pictorial stimuli, a probe consisting of a target and a distractor stimulus is presented that requires a response. The bias is thus assessed by RTs to targets at the location of predicted, but not actually presented, salient versus control stimuli. This avoids the bias on a given trial being dependent on the particular pair of stimuli selected from the salient and control categories – a participant may well have varying responses to particular exemplars, resulting in noisy data. Threat-related bias measures via the predVPT indeed showed relatively good split-half reliability compared to an equivalent dot-probe task (Gladwin, Möbius, Mcloughlin, & Tyndall, 2019); when the task design was optimized and trial numbers were increased, reliability reached psychometrically adequate levels for both threat-related bias, 0.70 (Gladwin & Vink, 2020) and alcohol-related bias, 0.74 (Gladwin, 2019). Further studies addressed the concern that systematic between-subject variance associated with individual differences related to the visual characteristics of the predictive cues might account for the high reliability (Gladwin et al., 2020; Gladwin, Figner, & Vink, 2019). An attentional bias modification training study using a training variant of the predVPT supported the interpretation that the bias involved anticipatory processes rather than merely conditioning of the initially neutral cues (Gladwin, Möbius, & Becker, 2019).

We note that the idea of an "anticipatory bias", which does not depend on the kind of stimulus-evoked response the traditional dot-probe task aims to measure, could perhaps be considered a theoretical oxymoron in terms of traditional dual-process models. We therefore briefly provide the rationale of this approach here. As more extensively discussed elsewhere, the core feature of these models is a controlled/reflective versus automatic/impulsive distinction (Diederich & Zhao, 2019; Kahneman, 2003; Schneider & Shiffrin, 1977; Strack & Deutsch, 2004), related to the intuitive sense that some parts of ourselves feel like they need to be kept under control, and other parts of ourselves need to do the controlling. Dual-process models describe this division in terms of the types of processing done by a reflective system versus an impulsive system. The reflective system consists of high-level cognitive functions that allow flexible, complex cognition and self-control, at the cost of being slow, effortful and error-prone; for instance, the manipulation of information in working memory, or the inhibition of a prepotent response. The impulsive system consists of lower-level functions that are simpler but fast, relying on previous learning experiences resulting in simple associations or immediate, "hard-wired" emotional responses; for instance, the quick classification of a half-seen shape as a spider or avoidance of painful stimuli. Although these models are very widely used, the claim that there is evidence for distinct systems or clearly separated sets of processes has been strongly criticized, as has the precision and adequacy of their theoretical constructs and terminology (Bellini-Leite, 2017; Gigerenzer & Regier, 1996; Grayot, 2020; Keren, 2013; Keren & Schul, 2009; Kruglanski & Gigerenzer, 2011; Osman, 2004). In response to this, a variation of dual-process models was developed, the Reprocessing and Reinforcement model of Reflectivity, the R^3 model (Gladwin et al., 2011; Gladwin & Figner, 2014; Wiers et al., 2013). This was a proof-of-principle redefinition of reflective versus automatic processing defined in terms of a response evaluation and selection cycle involving predicted outcomes, in which responses can include any kind of cognitive function (Dehaene & Changeux, 2000; Samejima et al., 2005; Samejima & Doya, 2007). A response evaluation and selection cycle can involve potentially multiple iterations of

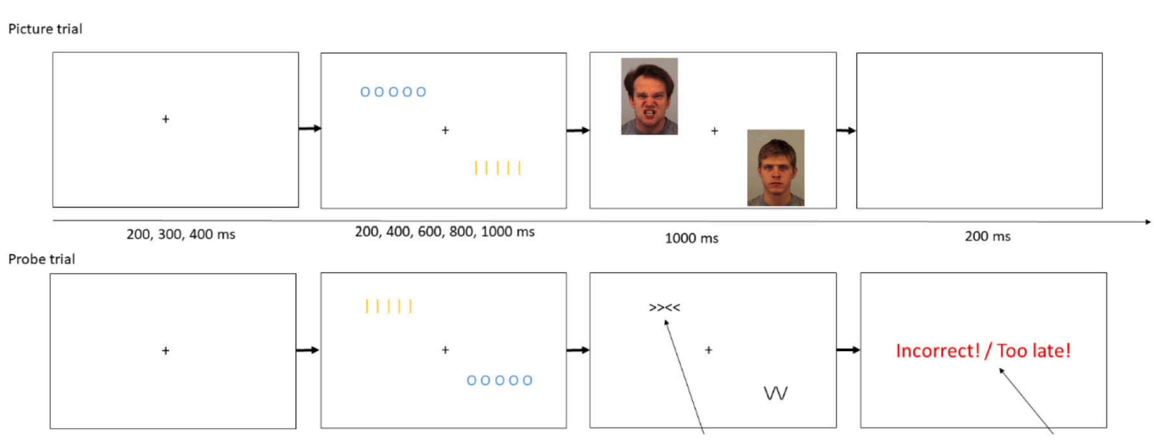

Fig. 1. Illustration of the task, using example stimuli from the Karolinska Directed Emotional Faces stimulus set (Lundqvist et al., 1988).

searching for and evaluating responses (Cunningham et al., 2007), which would strongly depend on temporal dynamics related to strengths of previously learned associations (de Wit & Dickinson, 2009; Dickinson & Balleine, 1995). A relatively reflective versus impulsive state of processing in this model means that a relatively large amount of reprocessing is allowed for response evaluation and selection. This model explicitly merely draws together strands of existing knowledge and ideas, e.g., from cognitive neuroscience (Bunge, 2004) and neo-behaviorism (Day, 1969; Moore, 1996), that were considered to be especially relevant for the evolution of dual-process models. In so doing the model emphasizes four conceptual points: first, "top-down" processes inherently depend on emotional and motivational processes that determine the goals such processes are used to achieve (Pessoa, 2009), and therefore these processes cannot be separated into separate systems; second, it is essential to avoid category mistakes by defining concepts at the correct level of emergence, in particular by distinguishing the more holistic state of reflectivity from specific component processes, any of which ultimately consists of obviously "automatic" information processing at the neural level; third, that "control" can be a consequence of a parameter of a system, in particular time allotted to search, rather than necessitating a separate system (Kruglanski & Gigerenzer, 2011); and fourth, that executive functions, complex cognition and reflectivity are at least in part a consequence of reinforcement and learning history, in the same way as other behaviours (Day, 1969; Diamond et al., 2007; Hazy et al., 2007; Miller & Cohen, 2001; Park et al., 2010; Wang et al., 2018), rather than a kind of "mental strength" or resource. While some views of dual-process models may consider automatic processes to be stimulus-driven and non-goal-directed by definition, the R^3 model thus allows for a wide range of ways in which asymmetries in cognitive processes could bias the outcome of (cognitive) response selection. In particular, if the predicted outcome of shifting attention to one or another location is more versus less attractive or aversive, this could involuntarily affect the response selection process. The predVPT was generated from, and derives its rationale from, this theoretical framework.

While the results of the predVPT are promising, previous studies have failed to control a particular task factor that may limit reliability and the ability to detect relationships with mental health: There has not been any attempt to experimentally control task-dependent influences on attention. In the traditional dot-probe task, there is no clear advantage or disadvantage to shifting attention towards or away from any given stimulus category. It is possible that associations between threat-related bias and individual difference variables will only reveal themselves when there is a particular relationship, e.g., conflict, between task-relevant versus automatic processes effects on attention. The present study therefore manipulated conflict between task-irrelevant emotional bias and the optimal direction of attention required by the task. The aim was to test whether this manipulation would (1) further improve the reliability of the predVPT, as the task-related component of attention would now be balanced rather than free to fluctuate per participant and (2) reveal, in exploratory analyses, associations with mental health-related individual differences in anxiety, depression, self-esteem, and aggression.

2. Methods

2.1. Participants

The sample consisted of 146 healthy adult participants who enrolled for credit or a small monetary reward. Three participants were removed for having a low overall accuracy, below 0.8. In the sample for analysis there remained 98 female and 45 male participants, mean age 25, SD = 8.8.

2.2. Materials

2.2.1. Predictive Visual Probe Task (predVPT)

The predVPT was programmed using JavaScript, PHP and HTML, and had the same trial structure as in previous work (Gladwin & Vink, 2020). There were two trial types, randomly selected per trial: Picture and Probe trials. Both trial types started with 150, 200, or 250 ms (randomly selected with equal probability) of a fixation cross. Then predictive cues were presented for 400 ms, which were the symbols OOOOO and XXXXX. One of these (randomized per participant) was coloured yellow (RGB values 250, 250, 10) and the other light blue (RGB values 10, 250, 250). The cues were placed either in the top-left and bottom-right quadrant of the screen (one cue at each position, at random), or on the bottom-left and top-right quadrant of the screen; the used quadrants alternated per trial. From this point on, the two trial types diverged. On Picture trials, one of the cues was replaced by an angry face, and the other by a neutral face; which cue was followed by which expression was consistent within each participant and randomized over participants. Faces were drawn from 36 faces of the Karolinska Directed Emotional Faces set (Lundqvist et al., 1988). Pictures were shown for 1000 ms. Trials ended with an inter-trial interval of 200 ms during which the screen was empty. On Probe trials, probe stimuli were presented instead of pictures. One probe was a target, >><<, the other a distractor, /\/\ or \/\/. The task was to indicate the location of the target by pressing the key associated with its location: R for top-left, F for bottom-left, J for bottom-right, and I for top-right. The fingers used were the index (bottom positions) and middle (top positions) finger of the left and right hands. Participants had a 1000 ms response window, which was ended by a response. Incorrect responses were followed by the text "Incorrect!" in red for 200 ms; if no response was provided in time the text "Too late!" was presented in the same way; accurate responses were followed by a 200 ms blank screen.

The difference with previous studies with this task was the manipulation of the probability of the target's location relative to cue locations, which differed between even and odd blocks (randomized per participant). On one set of blocks, towards-threat blocks, there was a 90% chance the target would appear at the location of the threat-predicting cue and 10% it would appear at the location of the non-threat-predicting cue. On the other set of blocks, away-from-threat, these probabilities were reversed. These probabilities were used to experimentally induce a task-related bias towards or away from threat, in addition to any automatic, task-unrelated bias involving threat.

2.2.2. Questionnaires

The 4-question Patient Health Questionnaire, PHQ4 (Kroenke et al., 2009), was used to measure anxiety and depression symptoms. Cronbach's alpha was 0.74 for anxiety and 0.74 for depression. Self-esteem was measured via the Rosenberg Self-Esteem Scale, RSES (Rosenberg, 1965). Cronbach's alpha was 0.90. The Buss-Perry Aggression Questionnaire, BP (Buss & Perry, 1992), was used to measure Physical Aggression (Cronbach's alpha = 0.86), Verbal Aggression (0.83), Hostility (0.86), and Anger (0.87).

2.3. Procedure

The experiment was performed online. Participants first completed the questionnaires, followed by two training runs of the predVPT (each two blocks of 48 trials) and then the assessment run of the predVPT (16 blocks of 48 trials). Following each run, participants were given awareness checks in which they were asked which of the cues was followed by the angry face.

2.4. Preprocessing and statistical analysis

During preprocessing of the assessment run used for analyses, the following trials were removed: The first four trials of the run, the first trial per block, error trials, trials following an error, and trials with an RT more than 3 SD away from the mean of the experimental condition the trial was in. Of the remaining probe trials, the median RT per condition was used for further analyses. These preprocessing steps were the same as those used in recent similar studies on the predVPT (Gladwin, Banic, Figner, & Vink, 2019; Gladwin & Vink, 2020).

The following analyses were performed for RT in Matlab (The Mathworks, 2015). Within-subject effects of block type (towards-threat and away-from-threat) and probe location (threat versus non-threat) were tested using the teg_RMA repeated measures ANOVA toolbox (Gladwin, 2020). These tests were also performed for accuracy. Split-half reliability was calculated using Spearman-Brown correction for the Spearman correlations between the bias on even and odd trials; bias was calculated per participant as the RT-difference between probe trials when the probe appeared at the threat minus the non-threat cue location. This means that a more negative bias score represents a stronger attentional bias towards the threat-related location. The bias was calculated over all blocks and per block type, and additionally the contrast score (bias for towards-threat blocks) – (bias for away-from-threat blocks) was calculated. Spearman correlations were used to test associations between this set of bias measures and the set of self-report measures (anxiety, depression, self-esteem, physical aggression, verbal aggression, anger, and hostility). Multiple correction was performed over the tested correlations using permutation testing. This provided two approaches to controlling false positives. First, a permutation-based estimate was acquired of the *p*-value criterion needed for a familywise error rate of 5%. The set of bias scores were randomly permuted and then correlated with the set of self-report measures. For each of 25,000 iterations, the smallest of the *p*-values of the correlations of the permuted data set was stored, leading to a null-hypothesis distribution of minimum *p*-values. The 5th percentile of these values was used as the p-criterion with familywise error correction, as fewer than 5% of random samples would have any test with a p-value below this value. Note that due to the exploitation of dependence between variables in the permutation procedure, this approach can result in less loss of power than Bonferroni correction. Second, using the same permutation procedure, we tested the significance of the number of nominally significant correlations ($p < .05$), as in previous work (Gladwin & Vink, 2018). This allows detection of effects at the level of the set of tests, trading off specificity for power: tests do not need to achieve very low p-values, but we cannot claim that any particular test achieved familywise corrected significance as with the permutation-based familywise error correction.

3. Results

Descriptive statistics are provided in Table 1.

Significant within-subject effects on RT were found for probe location, $F(1, 142) = 10.15$, $p = .0018$, eta_p^2 = 0.067, and for the interaction between probe location and block type, $F(1, 142) = 52.65$, $p < .0001$, eta_p^2 = 0.27. The interaction reflects the experimental induction of a task-induced bias due to the likely target location on the current block. The main effect of probe location represented a bias towards the threat location (513 ms versus 523 ms) over both block types.

The reliability of bias scores was high for the overall bias, 0.90. The reliability of the bias separated per block type was 0.59 for away-from-threat blocks and 0.73 for towards-threat blocks. The reliability of the contrast between the bias in the two block types was 0.50. The high reliability of 0.90 for the overall bias was explored further to check for effects of outliers (although the use of Spearman's rather than Pearson correlation would have reduced their influence). On visual inspection a clear outlier was found with unusually large bias scores, but removal of this datapoint hardly changed the reliability, which become 0.89 (Fig. 2).

A list of all pairwise correlations between all variables is provided in Supplementary material. The permutation procedure provided a p-value criterion of 0.0086 for familywise error correction. Two correlations were significant at this level: the overall bias and anxiety, $r = 0.23$, $p = .0053$, and the bias in away-from-threat blocks and anxiety, $r = 0.25$, $p = .0024$. The number of nominally significant tests was also significant; there were 4 significant tests, $p = .0071$, consisting of the two correlations involving anxiety, and further those between the bias in away-from-threat blocks and depression, $r = 0.21$, $p = .013$, and the bias in away-from-threat blocks and self-esteem, $r = -0.18$, $p = .027$. Taken together, the results suggest that increased anxiety, increased depression, and lower self-esteem were all related to a tendency to avoid upcoming threat when this was in line with task-relevant contingencies; with the evidence being strongest for anxiety.

Table 1
Descriptive statistics.

A. Self-report measures	
Variable	Mean (SD)
Anxiety	3.66 (1.42)
Depression	3.34 (1.34)
Self-esteem	3.09 (0.547)
Physical aggression	21.91 (9.54)
Verbal aggression	17.34 (6.21)
Anger	18.76 (7.87)
Hostility	20.86 (9.24)
Awareness check T1	0.60
Awareness check T2	0.92
Awareness check T3	0.96

B. RT and accuracy on the predVPT	Non-threat		Threat	
	Away	Towards	Away	Towards
RT	512	533	525	501
Accuracy	0.96	0.94	0.95	0.97

Note. Table 1A shows descriptive statistics for the scales of the self-report measures and the accuracy for the three awareness checks asking about which cue predicted the location of threat stimuli. Table 1B shows performance data for the predVPT task: the mean (over participants) of the median (over trials) RT and mean accuracy per condition. Non-threat and threat refer to whether the probe appeared at the location of a cue predicting non-threat or threat pictures. Away and Towards refer to block type: Is the experimentally induced task-related bias (based on the block's probe-location probability) towards or away from the threat location?

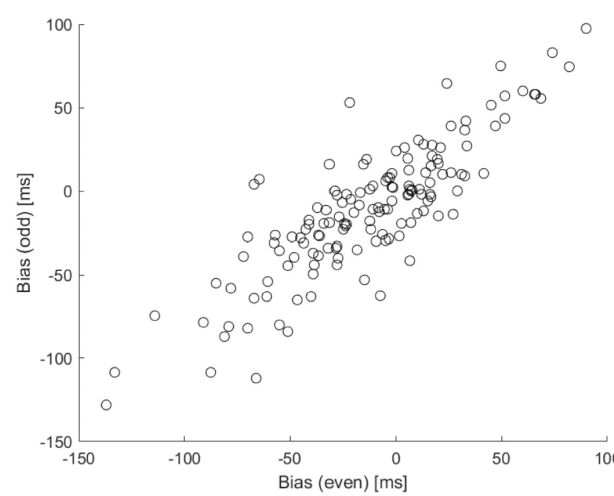

Fig. 2. Scatterplot of the even-uneven trial bias scores, after removal of one outlier. The split-half reliability was 0.89.

4. Discussion

The current study used a version of the predVPT in which the relationship between an emotion-related attentional bias and a task-related attentional bias was manipulated. This was expected to improve reliability by controlling the degree to which participants might direct attention in a voluntary way. Further, relationships with individual differences in mental health-related variables were explored.

Reliability of the overall bias was high, increasing to 0.9 using the current version with improved experimental control of the task-related bias from the 0.7 previously found using the predVPT (Gladwin, 2019; Gladwin & Vink, 2020). Reliability for the bias when calculated separately for sub-conditions was lower, which is as expected given the decrease in trial numbers; however, these were still in the 0.5–0.7 range and hence relatively high compared to the very low range reported for usual measures of spatial attentional bias. The current findings on overall bias in particular thus continue the improvement of reliability of the bias, due to attention to specific task features, in this case the experimental control of the task-relevant benefits to bias in one or the other direction. With the current reliability, the bias would be an adequate measure to use in individual differences research. Notably, this was found with online data collection, which may be important in a general pragmatic sense but also in terms of equality and inclusivity as not all researchers will have easy access to labs or eye-tracking equipment.

The current results in fact included correlational effects. Using strict multiple testing correction, anxiety was associated with avoidance of the predicted threatening stimuli. This was found using the overall bias, but the effect was carried by the bias in blocks in which the task-related bias was congruent with this avoidance. It thus appears that, in the sampled population, the anxiety-related bias was obscured when the participant was using an incompatible task-relevant bias. Also within blocks with a task-relevant bias away from threat, trends were found for depression and self-esteem: depression and lower self-esteem, like anxiety, involved avoidance. While anxiety is often associated with vigilance towards threat, excessive avoidance of aversive stimuli has also been linked to mental health disorders (Dempsey et al., 2000; Lavy & van den Hout, 1994; Maia, 2010; Mogg et al., 2004; Moukheiber et al., 2010). The avoidance of predicted, rather than already presented, threatening stimuli could, speculatively, reflect a possible coping strategy used by anxious individuals. In line with such a strategy, directing visual attention away from conflicting information downregulates its salience (Wadlinger & Isaacowitz, 2008) and reduces the startle effect (Singh et al., 2020). Thus, in terms of R^3-defined automaticity, the bias involves selecting an attentional response that will reduce the impact of threatening stimuli. This bias may be involved in anxiety, depression, and self-esteem, but to measure it appears to require the manipulation of the interaction between task-related and task-unrelated attentional biases.

The current study only included awareness checks concerning the consistent cue-picture mapping, which indicated that subjects strongly tended to develop awareness (possibly partly due to the checks themselves). It is therefore not known whether participants were aware of the alternating cue-probe (or predicted picture-probe) mapping. Although this novel task feature appeared to improve psychometric properties and reveal relationships with individual differences, it is uncertain how it might have changed the task and processes underlying the bias relative to previous versions of the task with random probe locations. The average bias over alternating blocks is not equivalent to the bias over blocks with no such contingency at all; for example, alternating contingencies may train participants to attend to contingencies and predictive stimuli (Gladwin, 2017). While the current rationale focused on the control of task-relevant, probe-related attentional influences, future research is needed to test hypotheses on potential mechanisms underlying the effect of this task factor. Relevant processes could include, for instance, whether conflict was evoked between the "top-down" and "bottom-up" influences on attention (i.e., the predictions of emotional pictures and of task-relevant probes and their use in response selection mechanisms), which could have influenced conflict monitoring processes relevant to effects of emotional stimuli (Bishop, 2009; Botvinick et al., 1999); differences between individuals' ability to use task-relevant predictive cues in the different block contexts; or differences related to the downregulation or inhibition of the influence of emotional stimuli (Oei et al., 2009).

Other limitations of the study include the convenience sample. Especially given the good reliability and promising correlational relationships, it would appear worth investing in studies using the predVPT in samples focusing on particular mental health issues in future research. Clear confirmatory hypotheses could be used based on the current results on anxiety, depression, and self-esteem. Another limitation was the online data collections. However, it has been found that data collected online do not show extreme differences from those collected in the lab (Chetverikov & Upravitelev, 2016; Gosling & Mason, 2015; van Ballegooijen et al., 2016). It is perhaps worth noting that participant behaviour in the lab is also not always ideal, and the lab itself is an abnormal setting. Together with considerations of pragmatism, we would suggest that online data collection and behavioural measures are a valid part of a broad, coherent approach to data collection which should of course also include laboratory measurements and, e.g., eye tracking or physiological methods. Future research is also needed to assess test-retest reliability over multiple sessions, as psychological test-retest effects may lead to divergent results from the current assessment of split-half reliability. There are also many potential variations of the task, in particular the stimuli and stimulus categories and the duration of trial intervals. While the current task produced good results, future research is needed to expand knowledge of the biases found elsewhere in the feature space of the task. In particular temporal dynamics, and hence trials or blocks with varying Cue-Probe Intervals, are of interest from the R^3 perspective. Finally, we note that the relationship is uncertain between effects found using the current task and the usual dot-probe task, and more broadly with other variations or alternative tasks (Grafton et al., 2021; Heitmann et al., 2021). Performance-related measures derived from broadly similar tasks do not necessarily reflect the same processes or biases, and generally have multiple potential explanations. For instance, effects on a given task may be due to an ability to disengage spatial visual attention from a salient stimulus, while on another task effects may be due to predictive processing driving attentional shifts. Research aimed at such comparisons will hopefully provide rich empirical information helpful for theoretical progress, but this will in any case require solid methodological foundations.

In conclusion, high reliability of anticipatory spatial attentional bias to threat was found when task-related attentional bias was controlled. Anxiety, and to a lesser extent depression and low self-esteem, were associated with a tendency to avoid predicted threatening stimuli. The results confirm and extend results demonstrating that high reliability of an implicit measure of spatial attentional bias can be achieved via online behavioural data collection, although this requires adjustments of traditional tasks and theoretical rationales.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2021.103357.

Declaration of competing interest

The authors declare no conflict of interest and received no funding from an external source.

References

Ataya, A. F., Adams, S., Mullings, E., Cooper, R. M., Attwood, A. S., & Munafò, M. R. (2012). Internal reliability of measures of substance-related cognitive bias. *Drug and Alcohol Dependence, 121*(1–2), 148–151. https://doi.org/10.1016/j.drugalcdep.2011.08.023

van Ballegooijen, W., Riper, H., Cuijpers, P., van Oppen, P., & Smit, J. H. (2016). Validation of online psychometric instruments for common mental health disorders:

A systematic review. *BMC Psychiatry, 16*(1), Article 45. https://doi.org/10.1186/s12888-016-0735-7

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin, 133*(1), 1–24. https://doi.org/10.1037/0033-2909.133.1.1

Bellini-Leite, S. C. (2017). Dual process theory: Systems, types, mind, modes, kinds or metaphors? A critical review. *Review of Philosophy and Psychology, 9*(2), 213–225. https://doi.org/10.1007/s13164-017-0376-x

Bishop, S. J. (2009). Trait anxiety and impoverished prefrontal control of attention. *Nature Neuroscience, 12*(1), 92–98. https://doi.org/10.1038/nn.2242

Botvinick, M., Nystrom, L. E., Fissell, K., Carter, C. S., & Cohen, J. D. (1999). Conflict monitoring versus selection-for-action in anterior cingulate cortex. *Nature, 402*(6758), 179–181. https://doi.org/10.1038/46035

Brown, H. M., Eley, T. C., Broeren, S., MacLeod, C. M., Rinck, M., Hadwin, J. A., & Lester, K. J. (2014). Psychometric properties of reaction time based experimental paradigms measuring anxiety-related information-processing biases in children. *Journal of Anxiety Disorders, 28*(1), 97–107. https://doi.org/10.1016/j.janxdis.2013.11.004

Bunge, S. A. (2004). How we use rules to select actions: A review of evidence from cognitive neuroscience. *Cognitive, Affective, & Behavioral Neuroscience, 4*(4), 564–579. https://doi.org/10.3758/CABN.4.4.564

Buss, A. H., & Perry, M. (1992). The aggression questionnaire. *Journal of Personality and Social Psychology, 63*(3), 452–459. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1403624.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research, 51*(13), 1484–1525. https://doi.org/10.1016/j.visres.2011.04.012

Chapman, A., Devue, C., & Grimshaw, G. M. (2019). Fleeting reliability in the dot-probe task. *Psychological Research, 83*(2), 308–320. https://doi.org/10.1007/s00426-017-0947-6

Chetverikov, A., & Upravitelev, P. (2016). Online versus offline: The Web as a medium for response time data collection. *Behavior Research Methods, 48*(3), 1086–1099. https://doi.org/10.3758/s13428-015-0632-x

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review, 30*(2), 203–216. https://doi.org/10.1016/j.cpr.2009.11.003

Cooper, R. M., Bailey, J. E., Diaper, A., Stirland, R., Renton, L. E., Benton, C. P., … Munafò, M. R. (2011). Effects of 7.5% CO_2 inhalation on allocation of spatial attention to facial cues of emotional expression. *Cognition and Emotion, 25*(4), 626–638. https://doi.org/10.1080/02699931.2010.508887

Corbetta, M., & Shulman, G. L. (2002). Control of goal-directed and stimulus-driven attention in the brain. *Nature Reviews Neuroscience, 3*(3), 201–215. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11994752.

Cunningham, W. A., Zelazo, P. D., Packer, D. J., & Van Bavel, J. J. (2007). The iterative reprocessing model: A multilevel framework for attitudes and evaluation. *Social Cognition, 25*(5), 736–760. https://doi.org/10.1521/soco.2007.25.5.736

Dalgleish, T., Taghavi, R., Neshat-Doost, H., Moradi, A., Canterbury, R., & Yule, W. (2010). Patterns of processing bias for emotional information across clinical disorders: A comparison of attention, memory, and prospective cognition in children and adolescents with depression, generalized anxiety, and posttraumatic stress disorder. *Journal of Clinical Child and Adolescent Psychology, 32*(1), 10–21. Retrieved from http://www.tandfonline.com/doi/abs/10.1207/S15374424JCCP3201_02.

Day, W. F. (1969). Radical behaviorism in reconciliation with phenomenology. *Journal of the Experimental Analysis of Behavior, 12*(2), 315–328. https://doi.org/10.1901/jeab.1969.12-315

Dear, B. F., Sharpe, L., Nicholas, M. K., & Refshauge, K. (2011). The psychometric properties of the dot-probe paradigm when used in pain-related attentional bias research. *The Journal of Pain: Official Journal of the American Pain Society, 12*(12), 1247–1254. https://doi.org/10.1016/j.jpain.2011.07.003

Dehaene, S., & Changeux, J. P. (2000). Reward-dependent learning in neuronal networks for planning and decision making. *Progress in Brain Research, 126*, 217–229. https://doi.org/10.1016/S0079-6123(00)26016-0

Dempsey, M., Stacy, O., & Moely, B. (2000). "Approach" and "avoidance" coping and PTSD symptoms in innercity youth. *Current Psychology, 19*(1), 28–45. https://doi.org/10.1007/s12144-000-1002-z

Diamond, A., Barnett, W. S., Thomas, J., & Munro, S. (2007). Preschool program improves cognitive control. *Science (New York, N.Y.), 318*(5855), 1387–1388. https://doi.org/10.1126/science.1151148

Dickinson, A., & Balleine, B. (1995). Motivational control of instrumental action. *Current Directions in Psychological Science, 4*(5), 162–167. https://doi.org/10.1111/1467-8721.ep11512272

Diederich, A., & Zhao, W. J. (2019). A dynamic dual process model of intertemporal choice. *The Spanish Journal of Psychology, 22*(e54), 1–13. https://doi.org/10.1017/sjp.2019.53

Gigerenzer, G., & Regier, T. (1996). How do we tell an association from a rule ? Comment on Sloman (1996). *Psychological Bulletin, 119*(1), 23–26. https://doi.org/10.1037/0033-2909.119.1.23

Gladwin, T. E. (2016). Attentional bias variability and cued attentional bias for alcohol stimuli. *Addiction Research and Theory, 25*(1), 32–38. https://doi.org/10.1080/16066359.2016.1196674

Gladwin, T. E. (2017). Negative effects of an alternating-bias training aimed at attentional flexibility: A single session study. *Health Psychology and Behavioral Medicine, 5*(1), 41–56. https://doi.org/10.1080/21642850.2016.1266634

Gladwin, T. E. (2019). Spatial anticipatory attentional bias for alcohol: A preliminary report on reliability and associations with risky drinking. *Alcoholism and Drug Addiction*. https://doi.org/10.31234/OSF.IO/WP6S5

Gladwin, T. E. (2020). An implementation of N-way repeated measures ANOVA: Effect coding, automated unpacking of interactions, and randomization testing. *MethodsX, 7*, Article 100947. https://doi.org/10.1016/j.mex.2020.100947

Gladwin, T. E., Möbius, M., & Becker, E. S. (2019). Predictive Attentional Bias Modification induces stimulus-evoked attentional bias for threat. *Europe's Journal of Psychology, 15*(3), 479–490. https://doi.org/10.5964/ejop.v15i3.1633

Gladwin, T. E., Banic, M., Figner, B., & Vink, M. (2020). Predictive cues and spatial attentional bias for alcohol: Manipulations of cue-outcome mapping. *Addictive Behaviors, 103*(106247), 1–6. https://doi.org/10.1016/j.addbeh.2019.106247

Gladwin, T. E., & Figner, B. (2014). "Hot" cognition and dual systems: Introduction, criticisms, and ways forward. In E. Wilhelms, & V. F. Reyna (Eds.), *Frontiers of cognitive psychology series: Neuroeconomics, judgment and decision making* (pp. 157–180). New York: Psychology Press.

Gladwin, T. E., Figner, B., Crone, E. A., & Wiers, R. W. (2011). Addiction, adolescence, and the integration of control and motivation. *Developmental Cognitive Neuroscience, 1*(4), 364–376. https://doi.org/10.1016/j.dcn.2011.06.008

Gladwin, T. E., Figner, B., & Vink, M. (2019). Anticipation-specific reliability and trial-to-trial carryover of anticipatory attentional bias for threat. *Journal of Cognitive Psychology, 31*(7), 750–759. https://doi.org/10.1080/20445911.2019.1659801

Gladwin, T. E., Möbius, M., & Becker, E. S. (2019). Predictive attentional bias modification induces stimulus-evoked attentional bias for threat. *Europe's Journal of Psychology* (In press).

Gladwin, T. E., Möbius, M., Mcloughlin, S., & Tyndall, I. (2019). Anticipatory versus reactive spatial attentional bias to threat. *British Journal of Psychology, 110*(1), 3–14. https://doi.org/10.1111/bjop.12309

Gladwin, T. E., & Vink, M. (2018). Alcohol-related attentional bias variability and conflicting automatic associations. *Journal of Experimental Psychopathology, 9*(2). https://doi.org/10.5127/jep.062317

Gladwin, T. E., & Vink, M. (2020). Spatial anticipatory attentional bias for threat: Reliable individual differences with RT-based online measurement. *Consciousness and Cognition, 81*, Article 102930. https://doi.org/10.1016/j.concog.2020.102930

Gosling, S. D., & Mason, W. (2015). Internet research in psychology. *Annual Review of Psychology, 66*, 877–902. https://doi.org/10.1146/annurev-psych-010814-015321

Grafton, B., Teng, S., & MacLeod, C. (2021). Two probes and better than one: Development of a psychometrically reliable variant of the attentional probe task. *Behaviour Research and Therapy, 138*, Article 103805. https://doi.org/10.1016/j.brat.2021.103805

Grayot, J. D. (2020). Dual process theories in behavioral economics and neuroeconomics: A critical review. *Review of Philosophy and Psychology, 11*(1), 105–136. https://doi.org/10.1007/s13164-019-00446-9

Hazy, T. E., Frank, M. J., & O'Reilly, R. C. (2007). Towards an executive without a homunculus: Computational models of the prefrontal cortex/basal ganglia system. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 362*(1485), 1601–1613. https://doi.org/10.1098/rstb.2007.2055

Heitmann, J., Jonker, N. C., & de Jong, P. J. (2021). A promising candidate to reliably index attentional bias toward alcohol cues–an adapted odd-one-out visual search task. *Frontiers in Psychology, 12*, 102. https://doi.org/10.3389/fpsyg.2021.630461

Kahneman, D. (2003). A perspective on judgment and choice: Mapping bounded rationality. *American Psychologist, 58*(9), 697–720.

Kappenman, E. S., Farrens, J. L., Luck, S. J., & Proudfit, G. H. (2014). Behavioral and ERP measures of attentional bias to threat in the dot-probe task: Poor reliability and lack of correlation with anxiety. *Frontiers in Psychology, 5*(DEC), 1368. https://doi.org/10.3389/fpsyg.2014.01368

Keren, G. (2013). A tale of two systems: A scientific advance or a theoretical stone soup? Commentary on Evans & Stanovich (2013). *Perspectives on Psychological Science, 8*(3), 257–262. https://doi.org/10.1177/1745691613483474

Keren, G., & Schul, Y. (2009). Two is not always better than one: A critical evaluation of two-system theories. *Perspectives on Psychological Science, 4*(6), 533–550. https://doi.org/10.1111/j.1745-6924.2009.01164.x

Kroenke, K., Spitzer, R. L., Williams, J. B. W., & Lowe, B. (2009). An ultra-brief screening scale for anxiety and depression: The PHQ-4. *Psychosomatics, 50*(6), 613–621. https://doi.org/10.1176/appi.psy.50.6.613

Kruglanski, A. W., & Gigerenzer, G. (2011). Intuitive and deliberate judgments are based on common principles. *Psychological Review, 118*(1), 97–109. https://doi.org/10.1037/a0020762

Kruijt, A.-W., Parsons, S., & Fox, E. (2019). A meta-analysis of bias at baseline in RCTs of attention bias modification: No evidence for dot-probe bias towards threat in clinical anxiety and PTSD. *Journal of Abnormal Psychology, 128*(6), 563–573. https://doi.org/10.1037/abn0000406

Lavy, E. H., & van den Hout, M. A. (1994). Cognitive avoidance and attentional bias: Causal relationships. *Cognitive Therapy and Research, 18*(2), 179–191. https://doi.org/10.1007/BF02357223

Lundqvist, E., Flykt, D., & Öhman, A. (1988). *The Karolinska directed emotional faces - KDEF, CD ROM from Department of Clinical Neuroscience, psychology section*. Karolinska Institutet.

MacLeod, C. M., Mathews, A., & Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology, 95*(1), 15–20. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/3700842.

Maia, T. V. (2010). Two-factor theory, the actor-critic model, and conditioned avoidance. *Learning & Behavior, 38*(1), 50–67. https://doi.org/10.3758/LB.38.1.50

Massa, A. A., Subramani, O. S., Eckhardt, C. I., & Parrott, D. J. (2019). Problematic alcohol use and acute intoxication predict anger-related attentional biases: A test of the alcohol myopia theory. *Psychology of Addictive Behaviours, 33*(2), 139–143. https://doi.org/10.1037/adb0000426

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

Miller, N. V., & Johnston, C. (2019). Social threat attentional bias in childhood: Relations to aggression and hostile intent attributions. *Aggressive Behavior, 45*(3), 245–254. https://doi.org/10.1002/ab.21813

Mogg, K., & Bradley, B. P. (1999). Orienting of attention to threatening facial expressions presented under conditions of restricted awareness. *Cognition & Emotion, 13*(6), 713–740. https://doi.org/10.1080/026999399379050

Mogg, K., & Bradley, B. P. (2006). Time course of attentional bias for fear-relevant pictures in spider-fearful individuals. *Behaviour Research and Therapy, 44*(9), 1241–1250. https://doi.org/10.1016/j.brat.2006.05.003

Mogg, K., Bradley, B. P., Miles, F., & Dixon, R. (2004). Brief report time course of attentional bias for threat scenes: Testing the vigilance-avoidance hypothesis. *Cognition & Emotion, 18*(5), 689–700. https://doi.org/10.1080/02699930341000158

Moore, J. (1996). On the relation between behaviorism and cognitive psychology. *Journal of Mind and Behavior, 17*, 345–368. Retrieved from https://www.jstor.org/stable/43853710?seq=5#metadata_info_tab_contents.

Moukheiber, A., Rautureau, G., Perez-Diaz, F., Soussignan, R., Dubal, S., Jouvent, R., & Pelissolo, A. (2010). Gaze avoidance in social phobia: Objective measure and correlates. *Behaviour Research and Therapy, 48*(2), 147–151. https://doi.org/10.1016/j.brat.2009.09.012

Naim, R., Wald, I., Lior, A., Pine, D. S., Fox, N. A., Sheppes, G., & Halpern, P. (2014). Perturbed threat monitoring following a traumatic event predicts risk for post-traumatic stress disorder. *Psychological Medicine, 44*(10), 2077–2084. https://doi.org/10.1017/S0033291713002456

Niu, Y., Todd, R. M., & Anderson, A. K. (2012). Affective salience can reverse the effects of stimulus-driven salience on eye movements in complex scenes. *Frontiers in Psychology, 3*(SEP). https://doi.org/10.3389/fpsyg.2012.00336

Oei, N. Y. L., Tollenaar, M. S., Spinhoven, P., & Elzinga, B. M. (2009). Hydrocortisone reduces emotional distracter interference in working memory. *Psychoneuroendocrinology, 34*(9), 1284–1293. https://doi.org/10.1016/j.psyneuen.2009.03.015

Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: Detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466–478. https://doi.org/10.1037/AXJ96-3445.130.3.466

Osman, M. (2004). An evaluation of dual-process theories of reasoning. *Psychonomic Bulletin & Review, 11*(6), 988–1010. https://doi.org/10.3758/BF03196730

Park, S. Q., Kahnt, T., Beck, A., Cohen, M. X., Dolan, R. J., Wrase, J., & Heinz, A. (2010). Prefrontal cortex fails to learn from reward prediction errors in alcohol dependence. *Journal of Neuroscience, 30*(22), 7749–7753. https://doi.org/10.1523/JNEUROSCI.5587-09.2010

Peckham, A. D., McHugh, R. K., & Otto, M. W. (2010). A meta-analysis of the magnitude of biased attention in depression. *Depression and Anxiety, 27*(12), 1135–1142. https://doi.org/10.1002/da.20755

Pessoa, L. (2009). How do emotion and motivation direct executive control? *Trends in Cognitive Sciences, 13*(4), 160–166. https://doi.org/10.1016/j.tics.2009.01.006

Posner, M. I. (1980). Orienting of attention. *The Quarterly Journal of Experimental Psychology, 32*(1), 3–25. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7367577.

Ravary, A., & Baldwin, M. W. (2018). Self-esteem vulnerabilities are associated with cued attentional biases toward rejection. *Personality and Individual Differences, 126*, 44–51. https://doi.org/10.1016/j.paid.2018.01.014

Rinck, M., & Becker, E. S. (2006). Spider fearful individuals attend to threat, then quickly avoid it: Evidence from eye movements. *Journal of Abnormal Psychology, 115*(2), 231–238. https://doi.org/10.1037/0021-843X.115.2.231

Rosenberg, M. (1965). *Society and the adolescent self-image*. Princeton, NJ: Princeton University Press.

Samejima, K., & Doya, K. (2007). Multiple representations of belief states and action values in corticobasal ganglia loops. *Annals of the New York Academy of Sciences, 1104*, 213–228. https://doi.org/10.1196/annals.1390.024

Samejima, K., Ueda, Y., Doya, K., & Kimura, M. (2005). Representation of action-specific reward values in the striatum. *Science, 310*(5752), 1337–1340. https://doi.org/10.1126/science.1115270

Schneider, W., & Shiffrin, R. M. (1977). Controlled and automatic human information processing: I. Detection, search, and attention. *Psychological Review, 84*(1), 1–66. https://doi.org/10.1037/0033-295X.84.1.1

Singh, L., Schüpbach, L., Moser, D. A., Wiest, R., Hermans, E. J., & Aue, T. (2020). The effect of optimistic expectancies on attention bias: Neural and behavioral correlates. *Scientific Reports, 10*(1), 1–13. https://doi.org/10.1038/s41598-020-61440-1

Soltani, A., & Koch, C. (2010). Visual saliency computations: Mechanisms, constraints, and the effect of feedback. *Journal of Neuroscience, 30*(38), 12831–12843. https://doi.org/10.1523/JNEUROSCI.1517-10.2010

Stefanics, G., Csukly, G., Komlósi, S., Czobor, P., & Czigler, I. (2012). NeuroImage processing of unattended facial emotions: A visual mismatch negativity study. *NeuroImage, 59*(3), 3042–3049. https://doi.org/10.1016/j.neuroimage.2011.10.041

Strack, F., & Deutsch, R. (2004). Reflective and impulsive determinants of social behavior. *Personality and Social Psychology Review, 8*(3), 220–247. https://doi.org/10.1207/s15327957pspr0803

The Mathworks. (2015). *MATLAB*. Natick, Massachusetts: The Mathworks, Inc.

Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology, 12*(1), 97–136. https://doi.org/10.1016/0010-0285(80)90005-5

Treue, S. (2003). Visual attention: The where, what, how and why of saliency. *Current Opinion in Neurobiology, 13*(4), 428–432. https://doi.org/10.1016/S0959-4388(03)00105-3

Van der Stigchel, S., Belopolsky, A. V., Peters, J. C., Wijnen, J. G., Meeter, M., & Theeuwes, J. (2009). The limits of top-down control of visual attention. *Acta Psychologica, 132*(3), 201–212. https://doi.org/10.1016/j.actpsy.2009.07.001

Wadlinger, H. A., & Isaacowitz, D. M. (2008). Looking happy: The experimental manipulation of a positive visual attention Bias. *Emotion, 8*(1), 121–126. https://doi.org/10.1037/1528-3542.8.1.121

Waechter, S., & Stolz, J. A. (2015). Trait anxiety, state anxiety, and attentional bias to threat: Assessing the psychometric properties of response time measures. *Cognitive Therapy and Research, 39*(4). https://doi.org/10.1007/s10608-015-9670-z

Wang, J. X., Kurth-Nelson, Z., Kumaran, D., Tirumala, D., Soyer, H., Leibo, J. Z., … Botvinick, M. (2018). Prefrontal cortex as a meta-reinforcement learning system. *Nature Neuroscience*, 1. https://doi.org/10.1038/s41593-018-0147-8

Wiers, R. W., Gladwin, T. E., Hofmann, W., Salemink, E., & Ridderinkhof, K. R. (2013). Cognitive bias modification and cognitive control training in addiction and related psychopathology: Mechanisms, clinical perspectives, and ways forward. *Clinical Psychological Science, 1*(2), 192–212. https://doi.org/10.1177/2167702612466547

de Wit, S., & Dickinson, A. (2009). Associative theories of goal-directed behaviour: A case for animal – Human translational models. *Psychological Research, 73*(4), 463–476. https://doi.org/10.1007/s00426-009-0230-6