# DEVELOPMENTAL TRAJECTORIES AND CORRELATES OF EXECUTIVE FUNCTION IN CHILDREN AND ADOLESCENTS WITH AUTISM SPECTRUM DISORDER

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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".

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## ABSTRACT

Executive function (EF; *set of high-order cognitive skills*) is a salient neuropsychological impairment present in several samples of children and adolescents with Autism Spectrum Disorder (ASD) and has been linked to ASD's social outcomes, including Theory of Mind (ToM; *ability to infer mental states*) and adaptive skills. However, understanding of the development of EF and its contribution to social outcomes in ASD is limited as research to date has rarely employed longitudinal designs while it has mainly focused on cool-cognitive EF, without including the hot-affective EF skills. The present thesis was the first to date to investigate the developmental trends of both hot and cool EF as well as "real-life" EF abilities (as rated by teachers) across childhood and adolescence in ASD and typical development. The EF developmental relations to ToM and adaptive skills were also examined across that broad age span (7-16 years) but a particular longitudinal focus was set on the links between EF and ToM across middle childhood (7-12 years). This original piece of research aimed to shed more light on the nature of the developmental pathway followed in ASD relative to typically developing peers across a broad age range and expand understanding of the neurocognitive impairments in EF that underpin crucial social and behavioural outcomes in middle childhood and adolescence in ASD. Overall, 170 children and adolescents (7-16 years), 91 controls and 79 with ASD, were assessed cross-sectionally. A smaller subgroup of children from the initial sample, aged between 7-12 years (37 controls and 45 with ASD) was followed after one year across middle childhood. Children and adolescents undertook tasks that assessed their cool EF (inhibition, working memory, planning), hot EF (affective decision making, delay discounting), ToM (false belief and mental state/ emotion recognition) and IQ ability at both time points. Teacher ratings of participants' "real-life" EF abilities and adaptive skills were also obtained at the first time point. It was found for the first time that both cool and hot EF linked with ToM in ASD and controls, with significant developmental improvements for selective cool and hot EF emerging across middle childhood. The expansion of the investigation of the developmental trends to adolescence in ASD revealed mainly a developmental pattern of declines or non-significant changes between younger children and adolescents for cool and hot EF (only cool inhibition showed improvements), suggesting that perhaps no dramatic EF changes occur beyond the age of 12 years in ASD. ToM and EF were still associated during adolescence in ASD and typical development. Cool and hot EF presented differentiated cross-sectional developmental trajectories and were found associated only in typical development suggesting that separable cool and hot domains of EF may be apparent in ASD. Finally, the development of "real-life" EF skills was found to also follow a differentiated pattern relative to performance-based, cool and hot EF skills, and only "real-life" but not performance-based EF predicted adaptive skills in ASD and typical development. Generally, with few exceptions (i.e. hot delay discounting), cool and hot EF of children and adolescents with ASD followed a deviant development compared to typically developing peers. The present research emphasised the importance of examining the development of cognitive skills (EF) and their links with behaviour in ASD as it may provide a better understanding of theoretical conceptualisations and inform diagnostic assessment and interventions. The organisation and developmental relationships of hot and cool EF within broad age ranges is a current, open topic of debate that the present thesis addressed. These findings may be crucial in overcoming the limitations of current theories of EF development and lead to a better understanding of the heterogeneity in neurocognitive impairments in ASD.

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## Introduction

Autism Spectrum Disorder (ASD) refers to a neurobiological disorder that significantly impairs children's social interactions, verbal and nonverbal communications, and difficulties adjusting behaviour to suit various contexts (Diagnostic and Statistical Manual of Mental Disorder— DSM-5, American Psychiatric Association, 2013). Over recent decades there has been a growing number of preschool and school-aged children diagnosed with ASD. The Special Educational Needs and Disability Regulations 2014 (UK) reported that the increase in diagnoses made may be due to greater awareness among practitioners and the public. The most dramatic increase has been among children aged between 3 and 10 years. This could be explained due to the wide range of distinct and inconsistent characteristics exhibited in autism across these ages. More specifically, the qualitative deficits both in social communicative and repetitive behaviours, found to be highly variable in childhood in ASD, (Eapen et al., 2015, p. 87) have now been used by specialists towards more in-depth diagnoses, classifications and epidemiology (Lecavalier, 2014, p.15).

However, the heterogeneous profile of strengths and weaknesses of children with ASD, along with the lack of developmentally appropriate screening tools, has resulted in poorly adjusted intervention programmes (Chowdhury, 2009). This has been found to hinder the consistent acquisition or generalisation of previously acquired skills in children with ASD (Griffith et al., 1999; Pennington & Ozonoff, 1996). Research has shown that an integrative neuropsychological assessment aimed at identifying children's unique developmental patterns could shed more light on effective intervention practices for children with ASD (Filipek et al., 1999; Joseph, 1999; Pennington & Ozonoff, 1996; Pennington & Welsh, 1995). Consequently, it is pivotal for developmental psychologists and education professionals to accurately determine the unique developmental pathways demonstrated in ASD across childhood, in order to enable children to achieve academic success and functional living to the best of their abilities (Filipek et al., 1999; Sparrow et al., 1997).

Despite several hypotheses constructed at biological and genetic levels, the primary cause of ASD is yet undefined as no individual hypothesis has been found to have stood up to rigorous evaluation (Riva, Bulgheroni, & Zappella, 2013). As studies have shown that young children with ASD may exhibit contradictory neuropsychological patterns of abilities/deficits based upon distinct factors such as genotype, age of onset of symptoms, and early intervention (Filipek et al., 1999), a single explanation for ASD should be abandoned (Happé, 2006). Thus, taking into consideration the multifaceted developmental nature of ASD, research following the development of children and adolescents with ASD may yield crucial knowledge. The present thesis aims to contribute to the existing knowledge regarding the neuropsychological developmental profiles of children and adolescents with ASD, crucially needed to ameliorate assessment policies and yield specialised interventions across all developmental components.

There are three dominant neuropsychological accounts of ASD: Executive Dysfunction hypothesis, Theory of Mind (ToM) hypothesis and Weak Central Coherence hypothesis. Executive Function (EF) is defined as the cognitive construct referring to the regulation of specific cognitive processes implicated in goal-directed, problem solving behaviour (Gioia, Isquith, & Guy, 2001; Goldstein, Naglieri, Princoptta, & Otero, 2014). There is a growing body of evidence reporting disruptions in EF in children and adults with ASD (van Eylen et al., 2015). This evidence contributed to the development of the Executive Dysfunction Hypothesis of ASD (Russell, 1997) which suggests that deficits in EF abilities play a key role in the behavioural manifestations of the autistic symptomatology. Although the Executive Dysfunction Hypothesis is one of the most influential theories, little work to date has investigated the developmental trends of EF abilities among children and adolescents with ASD.

The present thesis aims to shed more light on the development of EF within the spectrum and to examine the Executive Dysfunction Hypothesis in association with important social and behavioural outcomes (i.e. ToM abilities and adaptive skills) of children and adolescents with ASD. Specifically, it focuses on a differentiated view of EF as described by Zelazo and Müller (2002), in which a distinction is made between hot (affective) and cool (purely cognitive) EF components. The development of "real-life" EF skills (as reported by teachers' ratings) is also explored. In addition, a longitudinal component is included whereby the association between the development of hot and cool EF and ToM across time within ASD is explored. It should be noted at this point that ToM, although it is has been suggested in early research to be one of the potential neuropsychological accounts explaining ASD (along with EF and weak central coherence as described above), it has been exclusively treated as a separate cognitive construct (secondary to EF) rather than a neuropsychological account of ASD in the present study, with focus turning to its association with EF across time and development.

One of the main issues discussed within this thesis is the "hot and cool" EF distinction model (Zelazo & Müller, 2002). The present thesis is structured around this model, with distinct parts of the first chapter devoted to the executive processes of inhibition, working memory, and planning (cool EF aspects) as well as affective decision making and delay discounting (hot EF aspects). Along with the incorporation of the hot and cool EF model, the evaluation of EF is also crucially informed by behaviour-rating scales given to external raters such as the teachers of children and adolescents with ASD. The present study thus uses both performance–based measures and observational rating scales of "real-life" EF in order to investigate the impact of EF as a multifaceted cognitive domain on children's social development. The longitudinal component aids in illuminating whether EF contributes to long-term effects on ToM of children with ASD. Thus interventions may be more effective and increase functional independence of individual with ASD.

The identified prevalence of ASD has increased significantly especially during recent decades and resulted in a growing body of research regarding the efficacy of early intervention strategies. Results have demonstrated that the investigation of the relationship between cognitive impairments such as in EF and behavioural/social outcomes (i.e. ToM and adaptive skills) are critical for diagnosis and treatment of neurodevelopmental disorders, especially ASD (Frith, 2001; Klin, Saulnier, Sparrow, Cicchetti, Volkmar, & Lord, 2007; Klin, Saulnier, Sparrow, & Pennington, 2002; Pennington & Ozonoff, 1996). Thus, this study also examines the ToM construct and adaptive skills, considering their developmental relationship with EF skills in ASD and typical development.

## Overview of Thesis

The structure of this thesis is outlined within this section.

In Chapter One, a brief introduction to ASD followed by the background literature regarding the areas of focus in this thesis are presented. Previous research and theory on EF, developmental issues and ecological validity, its association to ToM, and adaptive skills in typical development and ASD are discussed. Definitions of and developmental trends in these cognitive constructs are provided. Following this, the association between EF, ToM, and adaptive skills as well as the ecological validity of the EF construct are discussed. The original contribution of this thesis to the literature along with the aims and research questions of the present thesis are presented at the end of Chapter One.

In Chapter Two the methodology of this thesis is outlined. The cross-sectional and longitudinal designs are described. Moreover, the sample, measures, and procedure are discussed as well.

In Chapters Three, Four, Five and Six the four studies that were conducted to address the aims of the present thesis are presented in detail. The first two studies are cross-sectional and longitudinal in design respectively and examine the cross-sectional and longitudinal links between hot and cool EF and ToM in school-aged children with and without ASD. They are based on data from middle childhood when children were between 7 and 12 years old. Chapter Three (Study One) presents the first study in the existing literature which investigates the relation between both cool and hot EF and ToM in school-aged children with and without ASD. Study Two, presented in Chapter Four, builds on the first study by exploring the longitudinal trends of hot and cool EF and their links to ToM after a year in these children between 7 and 12 years old with and without ASD.

The third and fourth studies, are both cross-sectional and build on the first two studies by expanding the age range of investigations in adolescence (beyond middle childhood). These studies focus on investigating the development of hot and cool EF in both children and adolescents, aged 7 to 16 years old, with and without ASD and also that of ecologically valid EF measures ("real-life" EF ratings), using a cross-sectional developmental trajectories approach. Developmental relations with ToM and other social outcomes, such as adaptive skills are also examined. More specifically, Chapter Five presents Study Three which employs a cross-sectional developmental trajectories approach to investigate the development of cool and hot EF in children and adolescents with and without ASD, aged 7-16 years old. Study Three focuses on the internal organisation and relation of cool and hot EF skills to one another as well. The predictive association of hot and cool EF to ToM in this broad age range is also explored in that study. Finally, Chapter Six presents Study Four which looks at the cross-sectional developmental trajectories of "real-life" EF skills as reported by teachers of children and adolescents with and without ASD, aged 7 to 16 years old. Furthermore, Study Four builds on Study Three as it compares the developmental trajectories of the two types of EF measures, "real-life" ratings and performance-based EF tasks (as tapped by the direct, neuropsychological assessment of participants in Study Three), especially focusing on which type is the stronger predictor of adaptive skills in children and adolescents with and without ASD. Within each separate study chapter there is an overview of the background literature specific to the focus of that relevant study, the methods used, the findings and a discussion of the results.

Chapter Seven presents the general discussion. This chapter aims to bring all findings from the four studies together and relate them to the research questions presented at the end of Chapter One. In addition, the contribution of these findings to the wider background literature is outlined. Chapter Seven concludes with the wider theoretical and practical implications of the research along with the limitations and future directions of the current research.

# CHAPTER I

## 1. Autism Spectrum Disorder

### 1.1 Profile, Prevalence, and Aetiology of ASD

Leo Kanner (Kanner, 1943) and Hans Asperger (Asperger, 1944) were the first to independently recognise autism as a developmental disorder. Their reports described individuals who demonstrated social and communicative deficits. Additionally, an early epidemiological study in London (Wing & Gould, 1979) indicated that children with autism aged between 0 and 14 years demonstrated three core deficits in verbal/nonverbal communication skills, in social understanding and imagination. These impairments were known as the triad of impairments in autism. ASD refers to a set of complex neurodevelopmental disorders that all share dominant social impairments, namely social and communicative impairments and unusually repetitive behaviours and stereotyped interests (DSM-5, American Psychiatric Association, 2013). ASD has been found to co-exist with a range of other conditions (Muhle, Trentacoste, & Rapin, 2004). More specifically, learning disability (IQ < 70) is significantly correlated with ASD and appears in 25–40% cases of the disorder (Baird et al., 2000; Chakrabarti & Fombonne, 2001) while other medical conditions such as epilepsy (Tuchman & Rapin, 2002), Fragile X syndrome (Rutter, 2000), and psychiatric disorders (deBruin et al., 2007) occur at high rates in ASD as well.

A considerable body of research has been conducted over the last two decades into the genetic factors influencing ASD with results showing that there may be a genetic subtype of autism (Bernier et al., 2014; Betancur, 2011). As research has not yet identified specific biological markers (Abruzzo et al., 2015; Hill, 2004), ASD is defined using behavioural criteria. Autism is described as a spectrum disorder since symptoms may manifest in the lower functioning end of the spectrum in which individuals demonstrate severe clinical and cognitive delays, up to the higher functioning end where individuals show no cognitive delays. The symptoms of ASD manifest differently in each child based on the age of symptom onset and developmental level. Usually early manifestations can be identified during toddlerhood (Zwaigenbaum, 2005). Research has shown that the vast majority of children with ASD were identified by parents/caregivers by 36 months of age (Baron-Cohen et al., 1996; Short & Schopler, 1988).

## Social impairments

ASD has been described as a neurodevelopmental disorder characterised by social dysfunction, communicative and imagination deficits (Volkmar et al., 2005). Social impairments involve mainly difficulties in initiating and maintaining social relationships: individuals, and especially children with ASD, often fail to engage with the reciprocal nature of social interactions and are subsequently unable to understand or follow social norms (VanMeter et al., 1997).

The developmental trajectory of verbal and non-verbal communication in ASD is characterised by delay and deviance. Specifically, individuals with ASD demonstrate profound delays in the acquisition of language and in some cases may never achieve spoken language (Tek et al., 2014). In addition, among individuals who develop language skills, communication is often affected by pragmatic difficulties, echolalia, stereotyped language (Baron-Cohen, 1988) or deficits in the processing of social cues (Pellicano, 2010). Significant deficits in the use of eye gaze and joint attention as communicative functions are common as well (Baron-Cohen, 1989; Leekam, Lopez, & Moore, 2000; McEvoy et al., 1993).

In terms of the lack of imagination, deficits are mostly manifested in the development of play skills. It is reported that the play of children with ASD is simple, stereotypical and repetitive, without the complexity or diversity that defines the play of typically developing children (Whyte & Owens, 1989). Although functional play may or may not be impaired (Baron-Cohen, 1987; Jarrold, Boucher, & Smith, 1994), children with ASD are unable to develop the skill of pretend play (Atlas, 1990; Baron-Cohen, 1987). These repetitive, stereotyped behaviours were traditionally discussed mainly within the framework of a neurological aetiology (Minshew, Sweeney, & Bauman, 1997), but later evidence has revealed relationships between these behaviours and selective brain processes such as inhibition (Joseph, 1999; Sparrow et al., 1997). Autism research thus moved from examining autistic symptomatology under a medical perspective to investigating links of such behaviours with specific cognitive domains; these will be discussed further in the present thesis.

Despite the limited quantity of social and communicative interaction in ASD, the core descriptions of this disorder refer to the quality of behavioural features rather than the quantity. More specifically, Capps et al. (1998) mention that the quantity of bids for communication individuals with ASD make is similar to typically developing peers, but these bids may take an inappropriate form. This distinction is known as the delay versus deviance theory and refers to a debate concerning the nature of development in several disorders including ASD. A child who is diagnosed with a developmental delay follows a trajectory of typical development; however, the developmental rate is significantly slower (VanMeter et al., 1997). In contrast, when a child exhibits deviance, the developmental trajectory presents differences both in the rate and sequence of progression (Spencer, 2013). Converging evidence suggests that children with ASD may follow a developmental trajectory characterised by elements of both delay and deviance (Spencer, 2013). In order for a diagnosis of ASD to be established, there needs to be the presence of deviant as well as delayed behaviours (Spencer, 2013).

Research focused on the autism spectrum has used ASD as a categorical label to define a single group of individuals; however an increasing body of evidence suggests that there is marked heterogeneity within the label (Le Couteur et al., 1996; Pellicano, 2012) and the broader description of the autistic phenotype (Bailey et al., 1998) due to the heterogeneity of the cognitive, social and behavioural outcomes across childhood in ASD. The developmental approach taken by this thesis may provide innovative descriptions of individual profiles of cognitive and social development within the autism spectrum.

**Prevalence**

ASD is a childhood psychiatric disorder (Bailey, Philips, & Rutter, 1996) with prevalence estimates to have presented a significant increase over the past four decades. In the late 70's the estimate of prevalence for ASD was 4 in 10,000 (Rutter, 1978). A review of the global estimate of prevalence of ASD carried out in 2012 found a median of 62 cases per 10,000 people (Elsabbagh et al., 2012). The prevalence of ASD worldwide has increased twentyfold since the epidemiological studies carried out between 1960 and 1970. By the 2000's the prevalence estimates were reported as being 1%-2% of all children (Blumberg et al., 2013) compared to the prevalence estimates of one in 2,500 children in the 1970s (Gillberg & Wing, 1999). Furthermore, a striking sex difference in prevalence rates has been also reported as males are more likely to be affected by ASD relative to females. Specifically, Newschaffer et al. (2007) mention that the male to female ratio is about 4.3:1. Finally, ASD can occur at every ability level. Although some individuals diagnosed with ASD demonstrate learning disabilities and intelligence quotients below 70, others present exceptionally high ability levels (Siegel et al., 1996), commonly referred to as high-functioning ASD.

### 1.1.2. Cognitive Theories of ASD

Several researchers have attempted to address the potential causes of ASD or understand the link between the brain and behaviour by investigating genetic, neurobiological and neuropsychological disciplines and their accounts. However, to date, no single level of explanation has been found to provide a successful account of ASD as the nature of this disorder seems to be so complex and multifaceted. Research so far suggests that genes and environment both play crucial roles in the emergence of ASD (Allred & Wilbur, 2002; Folstein & Rosen-Sheidley, 2001; Korvatska et al., 2002). Thus a multidimensional approach has been suggested as being most promising (Bailey et al., 1996). Happé explicitly states that "*Each psychological hypothesis (account) addresses part of the puzzle of autism, none would claim to have the complete story, and it may be that autism is the result of abnormalities in the development of several distinct systems*" (Happé, 2000, p.203).

Although it seems that an integrated model may be the most appropriate way of examining ASD, the elements of any multi-disciplinary account to be chosen have to be extensively investigated and evaluated, especially within the neuropsychological field that includes several competing theories of ASD. In psychological research, the neuropsychological account is mostly investigated including three dominant cognitive theories: The Weak Central Coherence, the Theory of Mind Deficit, and the Executive Dysfunction hypotheses. A more controversial theory called the extreme male brain theory of ASD, proposed by Baron-Cohen (2002) has also attracted research attention and will be briefly outlined.

Over the last two decades, studies investigating the aetiology of ASD have considered the neuropsychological account as a framework to explain the complexity of autism in children (Pennington & Ozonoff, 1996). A neuropsychological model accounts for both cognitive and developmental perspectives of the disorder, which has been argued as leading to a more accurate understanding of the various ASD manifestations (Filipek et al., 1999; Lord & Paul, 1997). The present study engages with the neuropsychological account explaining ASD, focusing specifically on the EF model supporting the critical link between brain and behaviour in ASD. The influence of EF on developmental landmarks, such as ToM and adaptive skills, is also examined.

### 1.1.3. The Weak Central Coherence theory

Weak Central Coherence Theory (WCC, Frith, 1989), also called Central Coherence Theory (CC), is a domain general process explaining some of the ASD social characteristics. More specifically, this theory suggests that there are different cognitive/ perceptual styles for context processing, with typically developing individuals processing information by focusing on the overall meaning within the context, whereas individuals with ASD present a weak drive for global coherence (Frith, 1989). Individuals with ASD seem to process information in a detail-focused way, focusing on the smaller distinct parts, rather than the whole (Frith & Happé, 1994). Thus, one of the key principles of WCC theory is that it may account for several non-social characteristics of ASD, such as the obsessive attention to precise detail. WCC theory had attracted ASD researchers' attention especially in the last two decades as it had been a topic in several studies that compared the central coherence skills of individuals with ASD to those of control groups. Studies in which the central coherence abilities were measured by visuospatial tasks confirmed the theory to a large extent. Specifically, it was reported that participants with ASD showed more accurate and faster performance than typically developing peers in tasks where a design/figure was supposed to be divided into its constituent parts. For example, individuals with ASD perceived more easily the constituent blocks of a design in an unsegmented condition of a Block Design Task (Ehlers et al., 1997; Happé, 1999; Shah & Frith, 1993). In addition, ASD individuals exhibited better performance in tasks where hidden shapes in various drawings had to be spotted and reported as quickly as possible (e.g., Embedded Figures Task) (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). Additionally, studies in which central coherence skills were measured with verbal or perceptual tests demonstrated that individuals with ASD tended to fragment perception (Happé, 1996; Jarrold & Russell, 1997) and thus benefit less from the context of meaning in sentences, narratives and memory tests (Jolliffe & Baron-Cohen, 1999).

Nevertheless, there has been no consensus about the validity of WCC theory due to mixed results from studies that contradicted some of its key tenets. For example, the performance of children with ASD in tasks measuring global-local processing was found to be similar to typically developing peers and peers with Tourette syndrome (Ozonoff et al., 1994). In addition, several later studies have also suggested intact holistic processing within the autism spectrum (Lopez & Leekam, 2003; Mottron et al., 1999, 2003). WCC Theory has evolved over time, with Frith's original idea being challenged in three main ways following the negative and mixed results of several studies (as discussed above). Specifically, the notion that WCC was a deficit in global processing has been replaced with the term superior local processing. Furthermore, the WCC hypothesis no longer suggests that individuals with ASD present a deficit either, but rather a cognitive bias (Happé, 1999). Importantly, individuals with ASD may demonstrate a bias to focus on details, but after effort may be capable of understanding the overall gist as well (Rajendran & Mitchell, 2007). Finally, WCC theory has changed in such way that it does not provide the grounds to explain all aspects of ASD, but is rather considered as one part of the cognitive style demonstrated by individuals with ASD (Happé & Frith, 2006).

### 1.1.4. The Theory of Mind Deficit

ToM is the ability to infer mental/ emotional states in order to predict and explain behaviour (Goldman, 2012). ToM is a multifaceted cognitive skill that develops gradually; its development emerges in infancy and continues to improve throughout middle childhood and adolescence. The understanding of false belief (i.e. understanding that one's belief/ representation about the world can contrast with reality), which is a critical aspect of ToM, measured by first-order false belief tasks, typically emerges at the age of 3-4 years (Schug et al., 2016). As children grow up, they present age-related performance gains and become capable of solving more complex, high-order ToM tasks (e.g. emotion recognition) across middle and later childhood (Devine & Hughes, 2013; Dumontheil et al., 2010). According to the ToM theory of autism, some individuals with ASD fail to fully develop the ability to attribute mental states at the level of beliefs, emotions, and goals (Premack & Woodruff, 1978) and that the ToM trajectory could follow either a delayed (Steele et al., 2003) or deviant (Peterson et al., 2005; Serra et al., 2002) pathway in ASD. Preliminary evidence regarding the establishment of the ToM deficit hypothesis emerged from studies using the unexpected transfer test of false belief (Wimmer & Perner, 1983). In this kind of task (e.g. Sally-Anne task), participants are instructed to witness a series of events which are mainly executed by dolls. More specifically, one of the dolls holds a belief regarding the location of an object that is not in line with its actual location. Then the participants have to determine where the doll will search for that item by inferring the mental state of the doll ("I think he thinks"; Rajendran & Mitchell, 2007). Baron-Cohen et al. (1985) were the first to introduce this theory three decades ago in an attempt to explain the core behavioural features -social and communicative symptoms- that characterise ASD. Results from their studies showed that the majority of children with ASD (80%) failed the classic Sally-Anne false-belief task as well as other related tasks (Baron-Cohen, Leslie, & Frith, 1985) used to measure ToM ability. This evidence of deficits in the acquisition of ToM provided a plausible explanation for autistic symptomatology, especially in relation to the impairments observed in social and verbal communication. Thus, ToM was considered as the first account to underpin the developmental and behavioural manifestations of ASD. These influential results were widely replicated with this task as well as other tests of false belief, suggesting that children with ASD have difficulty imputing mental states to themselves and others (see review of Tager-Flusberg, 2007). However, questions about the universality of ToM deficits in ASD and how this hypothesis could explain the earliest manifestations of ASD (e.g. lack of eye contact, sensory sensitivities, or restricted interests) emerged. Firstly, as false belief tests have been criticised for their heavy reliance on language, it is likely that potential deficits in language skills (associated with performance on false belief tasks) may result in individuals with ASD failing these tasks, despite having the ToM ability to successfully pass them (Bloom & German, 2000). Furthermore, a single test of ToM is also unlikely to integrate and/ or assess the variety of ToM skills. More specifically, Happé (1994) argued that since 20% of autistic individuals successfully passed false belief tasks, the ToM deficit did not appear to be universal. Such results raised concerns as to whether false belief tasks could identify subtle deficits in ToM skills as exhibited by individuals with high-functioning ASD (Rutherford, Baron-Cohen & Wheelwright, 2002). In addition, the ToM hypothesis did not provide the grounds to explain the repetitive/restricted behaviour patterns of ASD nor the characteristic islands of abilities of these individuals, such as their superior visual-attention skills (Tager-Flusberg, 2007). Finally, studies have shown that some individuals with ASD (adolescents and adults, particularly those individuals with high functioning ASD) demonstrate successful performance in first-order and second-order ToM tasks (Begeer et al., 2010; Dahlgren & Trillingsgaard, 1996; Ponnet et al., 2005; Roeyers & Demurie, 2010). Therefore, it has been suggested that the ToM deficit hypothesis cannot be considered as a comprehensive account of ASD. This does not question of course the adequate evidence to date suggesting that deficits in ToM in ASD emerge in several samples (especially in childhood) (Mathersul, McDonald, & Rushby, 2013; Peterson, Wellman, & Slaughter, 2012). As ToM is generally known (among other cognitive constructs) to develop atypically in ASD (Lantz, 2002), the purpose of the present section was mainly to highlight the significant issues which indicate that the ToM hypothesis cannot stand as the primary and sole account explaining ASD. The ToM deficit hypothesis revolutionised autism research and its legacy is undeniable, although its definition and theoretical underpinning have yet to be agreed upon (Rajendran & Mitchell, 2007). Other accounts of autism should integrate the concept of ToM deficits (which are unquestionable for some individuals with ASD) in their attempt to shed more light on the nature of the heterogeneity in neurocognitive impairments in ASD. Thus, although the present study was centred around the Executive Dysfunction hypothesis of autism, it also employed ToM abilities (as secondary to EF variables) in order to place more emphasis on the understanding of how such cognitive, ASD-related impairments inter-relate or influence one another in ASD. More details about ToM deficits and their association to EF in ASD are presented in the next sections.

### 1.1.5. Extreme male brain theory

Baron-Cohen (2002), through the extreme male brain theory, attempted to explain the autistic profile and potential causes, suggesting that individuals with ASD present weaknesses in empathising, but strengths in systemising, as well as a drive to analyse systems (Baron-Cohen, 2002). This theory was based upon Baron-Cohen's Empathising-Systemising Theory which classified individuals into cognitive profiles based on their abilities to systemise or empathise (Liu & Konkle, 2010). Systemising refers to analytical and deductive skills and the understanding of the rules of a system. Empathising on the other hand refers to the emotional and behavioural understanding which requires social and communication skills. Thus, according to Baron-Cohen (2002), ASD should be considered as the manifestation of an extreme male brain; the social and communication impairments exhibited by individuals with ASD could be explained by a deficit in empathising, while the detail-oriented behaviour could be a reflection of strength in systemising (Liu & Konkle, 2002). Besides this, it has been suggested that high levels of prenatal testosterone could be a significant risk factor accounting for the aforementioned hyper-masculinised cognitive profile of individuals with ASD (Auyeung et al., 2009).

The extreme male brain model is a controversial theory as the psychometric instruments and statistical procedures that were used in these studies have been a point of disagreement among researchers (Skuse, 2009). Nevertheless, this new knowledge has been an important step to establish the exploration of how biology can affect cognition, especially in ASD (Liu & Konkle, 2010).

It should be noted at this point that the ASD theories of: ToM deficit, Weak Central Coherence, and male brain hypothesis are beyond the scopes of this thesis and will not be examined further. However, as already discussed earlier (section 1.1.4.), ToM ability is included as a secondary variable to EF in the present study (outcome variable) in an attempt to determine the extent to which executive dysfunction influences the manifestation (e.g. deficits and/or development) of social outcomes such as ToM in ASD.

### 1.1.6. Theory of Executive Dysfunction in ASD

The EF account of ASD emerged as it was noticed that many of the symptoms of ASD (such as difficulty in switching attention, perseverative biases or lack of impulse control) presented similarities to symptoms that were linked with specific brain injury, mostly to what now is known as Dysexecutive Syndrome (DES, Baddeley, & Wilson, 1988) (Rajendran & Mitchell, 2007). These everyday behaviours reported among individuals with ASD were not successfully tackled by the other theories described above. The Executive Dysfunction theory is probably the most influential theory which has attempted to understand ASD; with several researchers suggesting that the symptoms manifested within the spectrum arise from early EF disruptions (Damasio & Maurer, 1978; Pennington & Ozonoff, 1996; Russell, 1997; Russo et al., 2007). Executive Dysfunction theory can be seen to underpin several of the crucial autistic features, both in the social and non-social aspect. The EF account suggests that ASD symptomatology is actually a manifestation of deficits in executive control over behaviour (Joseph, 1999). The investigation of EF as an influential factor in relation to autism symptomatology initially gained support due to an overlapping group of EF deficits associated with the restricted, repetitive behaviours (Griffith et al., 1999; Stone et al., 1999). Research also suggested that other impairments, such as language and social deficits could be also linked to EF disruptions (Ozonoff, Pennington, & Rogers, 1991; Stone et al., 1997). Potential abnormalities in the prefrontal cortex raised by damage in the cortical or subcortical brain structures (Pennington & Ozonoff, 1996) were suggested to account for the deficits in EF in individuals with ASD.

## 1.2. The construct of EF

EF has been found to be crucial to the development of children's behavioural and social abilities and is related to academic performance and social competence (Best, Miller & Jones, 2009). There has been a plethora of different definitions of EF put forward, but no single definition has been widely adopted yet. Generally, commonalities are evident across different definitions (De Luca & Laventer, 2008), as most define EF as an umbrella term including crucial, high-order, cognitive processes, in other words functioning as the brain's conductor. EF thus refers to a set of future-oriented and goal-directed cognitive skills that are crucial for problem solving and social behaviour, as well as the ability to organise oneself (Anderson, 1998; Gioia, Isquith, & Guy, 2001; Goldstein, Naglieri, Princoptta, & Otero, 2014). EF is thought to be responsible for controlling and directing one's cognitive capacities and emotional behaviour, in order to perform a purposeful, goal-directed activity (Anderson, 1998), pulling oneself away from the external context (Ozonoff, 1995). Thus, EF is vital for everyday behaviour, especially during problem-solving when having to face novel tasks (Anderson et al., 2008). Disruptions in EF, can be quite challenging for children as those with impaired EF may experience difficulties in school or home; impulsivity and disorganisation or inability to plan actions efficiently may be demonstrated (P. Anderson, 2008).

EF has been studied over the last sixty years (e.g. Luria, 1966; Piaget, 1954) and although there is still uncertainty about the precise nature of these component skills, another common theme across different definitions is that EF constitutes a complex, multifaceted construct, incorporating various cognitive processes that work together when needed (Peterson & Welsh, 2014). However, no definitive conclusions regarding which of these various processes should fall under the EF umbrella have yet been reached. There is, for that reason, an ongoing debate about whether EF skills are a unitary construct or a set of distinct domains. Evidence regarding this major theoretical issue is quite mixed to date. There is some research indicating that EF is best described as unitary construct, especially in early childhood (Fuhs & Day, 2011; Wiebe et al., 2008; Wiebe et al., 2011). This could mean that behavioural impairments following EF disruptions could be attributed solely to a single dysfunctional system (for instance deficits in working memory; Kimberg, D'Esposito, & Farah, 1997). In contrast, other accounts of EF highlight the independence of separable, but related, EF skills (Best et al., 2009; Diamond, 2006; Isquith, Gioia, & Espy, 2004). It should be noted that historically, researchers adopted a fractioned approach to the investigation of EF. Fuster (1985) was among the first to distinguish three components of EF, namely retrospective working memory, interference control and oriented planning. Welsh et al. (1991) also suggested a three-factor model of EF that included planning, hypothesis testing, and speeded responding (time to react to some signal), followed by Hughes (1998a) who also proposed working memory, inhibition and attentional flexibility as the dominant subcomponents of EF. However, as Pennington et al. (1997) suggested, these definition terms used by each author lack theoretical precision. For example, the term "attentional flexibility" seems to refer to inhibitory processes, whereas the "problem solving" invokes inhibition, error detection and set shifting. On the other hand, researchers such as Fodor (1983) have suggested that EF abilities should not be considered as being fractionated. In fact, during the 1990s his hypothesis led to researchers investigating the interaction between the different EF skills required to solve a problem. Rogers et al. (1994) suggested, for instance, that the probability of generating an incorrect prepotent answer is dependent upon a specific combination (interaction) between working memory and the strength of prepotency. Research carried out over the last two decades though has revealed that executive functions should be considered as separate yet integrated skills (Goldstein & Naglieri, 2013). One such influential model of EF organisation was proposed by Miyake et al. (2000). This model states that EF encompasses three separable domains, namely: *working memory* (the ability to store and manipulate information), *cognitive flexibility* (the ability to switch between thinking about two different concepts) and *inhibition* (the ability to inhibit irrelevant information and to withhold a dominant response in favour of another response). This three-factor EF model has been replicated and supported by later studies both in early childhood (Isquith et al., 2004) and middle childhood/ adolescence (Lehto et al., 2003). Building on this model, Diamond (2006) later suggested that these three main EF skills can form the basis for other more complex EF components to emerge, such as reasoning or planning. EF planning should not be overlooked as it is also critical for goal-orientated behaviour (Best et al., 2009) and involves the ability to plan actions in advance and execute them in a strategic and efficient manner (Anderson, 2002). Finally, another less widely adopted, three-factor EF model proposed by Gioia, Isquith, Retzlaff, and Espy (2002) argues that EF should include three distinct indices: *behavioural regulation* (e.g. inhibition), *emotional regulation* (e.g. emotional control, shifting) and *metacognition* (e.g. working memory, planning) in children and adolescents (5-18 years). The multifaceted nature of EF has also been supported by results of behavioural studies finding weak or non-significant patterns of correlations between several different EF tasks or multiple factors in factor analysis (Brocki & Bohlin, 2004; Lehto, 1996; Pennington et al., 1997; Welsh et al., 1991).To summarise, it should be borne in mind that the afore-mentioned models of EF identify separate EF abilities but all these cognitive skills suggested to form EF are used in affectively neutral situations.

EF is typically impaired in patients after acquired damage to the frontal lobes and in developmental disorders with congenital deficits in the frontal lobes, such as ASD, attention deficit hyperactivity disorder (ADHD), Tourette's syndrome, and obsessive compulsive disorder (OCD) (Ozonoff & Jensen, 1999). Although the behaviours regulated by EF are suggested to be mainly controlled by the frontal lobes and the prefrontal cortex in particular (Duncan, 1986), the neurocognitive processes underlying them are not fully understood to date (Zelazo et al., 2003).The prefrontal cortex refers to the region of the anterior cerebral cortex, expanding up to premotor cortex and including the supplementary anterior region as well (Stuss & Benson, 1986) that comprises between a quarter and a third of the cortex (Fuster, 1985). This brain region is suggested to control EF (Duncan, 1986). Research has demonstrated that the reciprocal connectivity of the prefrontal cortex with other more subcortical or posterior areas of the brain allows the prefrontal cortex to integrate cognitive information and regulate emotions, actions and thoughts (Zelazo & Müller, 2002). Evidence from neuroimaging studies examining the prefrontal cortex have provided further support to the view of a multi-faceted construct of EF: different EF components seem to be underpinned by different parts of the prefrontal cortex. For instance, inhibition tasks were found to activate areas of the orbitofrontal cortex (Aron, Robbins, & Poldrack, 2004) while working memory mostly relies on lateral prefrontal cortex areas (Narayanan et al., 2005). Furthermore, several differentiated accounts of prefrontal functions have been provided over the years emphasising the consequences of damage to different parts of the prefrontal cortex. More specifically, damage to the dorsolateral prefrontal cortex is traditionally associated with classic, so-called cool EF deficits such as working memory, inhibition or planning impairments (Damasio, 1996), while damage to the orbitofrontal cortex yields inappropriate behavioural and social outcomes with an affective component which can be considered as hot EF (Gazzaniga et al., 1998).

Early theories suggested that the prefrontal cortex was not functional during childhood. Luria et al. (1973) proposed that prefrontal cortex was not activated until about 4 to 7 years of age. Other researchers even argued that the prefrontal cortex was not functional prior to early adolescence, about 12 to 15 years and not fully functional until after the age of 24 years (Golden, 1981). However, evidence from imaging studies (Bell & Fox, 1992) and case studies of children with brain lesions or head injuries (Bell & Fox, 1992; Scheibel & Levin, 1997) demonstrated that the prefrontal cortex was functional from the end of infancy. Due to the assumed link between EF and this area of the brain, developmental theories of EF have generally been in parallel to theories of prefrontal function (Zelazo & Müller, 2002). EF emerges during the first year of life and continues to develop across early childhood with important changes occurring between 3-5 years. However, EF is relatively immature during childhood and continues to develop until adolescence (Fuster, 2000). EF was initially studied only from a neuropsychological perspective as researchers sought to define the neurological structure of EF (Zelazo & Müller, 2002) but the current focus is now placed on evidence from developmental psychology and developmental psychopathology.

### 1.2.1. Cool and Hot Executive Function

EF has been traditionally viewed through a purely cognitive lens considered to be elicited under relatively abstract, non-affective conditions. Thus, the role emotion and motivation play in EF (Peterson & Welsh, 2014) is often neglected. Developmentalists however suggest that EF should be conceptualised as a broader construct, as it includes affective control processes as well ("hot processes"; Zelazo & Müller, 2002). Metcalfe and Mischel (1999) were among the first to introduce the "hot–cool systems" distinction, proposing that hot processes are emotional influences on behaviour controlled by cool EF processes. Building on this initial model, Zelazo and Müller (2002) suggested a similar yet fundamentally different construct of EF that considers "hot" and "cool" processes as two distinct domains. They suggest that hot EF processes, along with their underlying neural systems differ from cool EF processes but may coordinate with them, according to each task's demands. Thus, EF varies as a function of motivational significance (Zelazo & Carlson, 2012). Cool aspects of EF involve processes (e.g. working memory, inhibition, planning) operating in affectively neutral contexts (Zelazo & Carlson, 2012), while hot EF aspects refer to top-down processes that operate in emotional or motivational situations, elicited when one attempts to solve a problem with meaningful consequences for oneself (Zelazo, Qu, & Müller, 2005). Hot EF processes include aspects such as delay of gratification or delay discounting (i.e. the ability to give up on immediate smaller rewards in order to obtain later larger rewards) (Carducci, 2009) and affective decision making (the tendency to make choices between different options under risk), that have motivationally significant consequences, such as meaningful rewards and losses (Kerr & Zelazo, 2004). Several tasks have been validated as measuring hot EF. Specifically, most hot tasks tapping impulsivity control (e.g. delay of discounting task, gift wrap task) include an emotional component that children and adolescents have to overcome in order to successfully problem solve (Zelazo & Carlson, 2012). For example, in the Delay of Gratification paradigm, a task used to measure hot EF, children have to choose whether they want "one marshmallow now or two of them at the end of the game" (Thompson, Baressi, & Moore, 1997). Young children do not choose the obvious bigger prize of two candies at the end of the assessment (Mishel, Shoda & Rodriguez, 1989) although they grasp the concept of "more" and "less" (Papalia & Olds, 1989).Therefore, it is suggested that despite the marshmallow test being a rule-based problem, it also involves an emotional component that interferes with children ability to respond correctly. Hot EF is suggested as being more central for self and social understanding problems. Social situations are by nature more motivationally significant considering the fact that people's behaviour during social interactions involves emotional or motivational significance for those involved (Zelazo & Müller, 2002; Zelazo et al., 2005). On the other hand, the cool system is characterised as purely cognitive. It is related to self-control and specialised for "complex spatiotemporal and episodic representation and thought" (Metcalfe & Mischel, 1999, p.5). Cool EF includes aspects such as inhibition, working memory, cognitive flexibility, and planning, skills that in other words have been historically perceived to encompass EF. In contrast to hot EF tasks, measures that tap cool EF do not have obvious emotional implications. Some of the most classic paradigms include the Stroop Test (Stroop, 1935), the Digit Span (Wechsler, 1991), and the Tower of London (Shallice, 1982). For example, in the Stroop test participants are presented with the names of specific colours written with a non-matching ink and they are asked to read aloud the colour of the ink, inhibiting the reading of the actual word (Stroop, 1935).

Research regarding the organisation and development of hot EF lags behind that for cool EF as it was only recently (last two decades) that studies took hot EF into consideration as well (Peterson & Welsh, 2014). Relevant evidence, especially regarding hot EF organisation is mixed to date. Some studies seem to perceive that social-cognitive abilities such as morality, emotional intelligence or even ToM are hot EF domains (e.g. V. Anderson et al., 2008; Zimmermann et al., 2016) whereas other researchers argue that these abilities are simply related to and not reflective of hot EF (e.g. Zelazo, Qu, & Müller, 2005). The need for further clarification of the relation between such social abilities (e.g. ToM) and hot EF is addressed in the present study.

This proposed distinction between hot and cool EF is suggested to have a biological basis supporting the view that distinct EF abilities can be identified (Happaney et al., 2004; Zelazo et al., 2005). Evidence from neuroimaging studies has shown that there are two distinct brain areas to be activated for problem-solving activities; namely the orbitofrontal cortex and the dorsolateral prefrontal cortex (Bechara et al., 1994; Bush, Luu, & Posner, 2000). Hot EF is proposed to be controlled by the orbitofrontal cortex and related medial regions (Bechara, 2004). Cool EF aspects may be connected with the dorsolateral regions of the prefrontal cortex as they engage with the cognitive processing (Brock et al., 2009). Ward et al. (2006) suggest that individuals who have suffered injuries to the brain area underpinning cool EF are no longer able to learn novel information or problem solve whereas brain damage to regions responsible for hot EF evokes impulsivity and inappropriate behaviour. The orbitofrontal and medial prefrontal cortices belong to the frontostriatal circuit, which has been shown to share significant relations with the amygdala and the limbic system. The latter brain areas may underlie abilities such as emotional and social processing (Happaney et al., 2004). The dorsolateral prefrontal cortex of cool EF in contrast, has not been found to share any direct connections with the limbic system (Zelazo & Müller, 2002; Zelazo et al., 2005). It should be noted that these neural bases of both cool and hot EF may be distinct but work together or interact in certain situations, as a part of a general, integrated system (Zelazo et al., 2005). More specifically, it is likely that in order to solve an emotional or motivational problem (“hot” context), its evaluation in a neutral, decontextualized framework (using “cool” processes), may be proven more successful (Zelazo et al., 2013). Further evidence from neurological studies demonstrating a dissociation between hot and cool EF in adults provides more support to Zelazo and Müller’s (2002) proposition of separable, distinct EF. Bechara et al. (1998) reported that adults (24-68 years) with lesions to the ventromedial prefrontal cortex presented deficits in hot affective decision making but an intact cool working memory ability. Furthermore, adults with lesions in the dorsolateral prefrontal cortex exhibit the reverse pattern of dissociations. Taking this together, it could be suggested that a double dissociation between these abilities may emerge, supporting the notion that they are linked to different prefrontal cortex areas. Moreover, findings from a more recent study also supported the hot-cool EF distinction, as it showed that adults (18-68 years) with traumatic brain injury presented deficits in hot affective decision making, but no impairments in cool inhibition (Fonseca et al., 2012). It should be noted though that this pattern of dissociation was present only in adult samples and the organisation of hot and cool EF in childhood or adolescence may differ. As the evidence of a two-factor EF model (hot & cool) in younger ages (early childhood) is very limited to date (Kim et al., 2014; Willoughby et al., 2011), more research needs to be focused on understanding the development and organisation of this mainly theoretical EF model in childhood and adolescence.

The distinction of hot and cool EF was employed in the present thesis as it is crucial to adopt a broader conceptualisation of EF that can reflect not only the purely cognitive but more affective/ motivational aspects as well. Investigating cognitive development from this perspective, could allow EF to be extended outside the laboratory, into more “real-life” decision making and problem solving in which rewards and emotions play a key role in childhood and adolescence. The impact of EF on aspects of social cognition, such as ToM or adaptive skills, could be better established (Peterson & Welsh, 2014; Zelazo & Carlson, 2012). Besides this, a multidimensional EF model (hot and cool factors) has been shown to have a greater model fit than a uni-dimensional model in explaining and predicting social behavioural problems in typically developing children (Kim et al., 2014). This type of model, incorporating affective and emotional elements that typically work together as part of a more general adaptive function (Zelazo & Carlson, 2012) is also used, as it is useful in shedding more light on the roles of specific EF in clinical populations, such as ASD (Hongwanishkul, Happaney, Lee, & Zelazo, 2005). Zelazo and Müller (2002) have suggested that ASD might be a neurodevelopmental disorder with primary deficits in hot EF and secondary impairments in cool EF (Dawson, Meltzoff, Osterling, & Rinaldi, 1998). No study to date has investigated the simultaneous development of hot and cool EF in an ASD population.

### 1.2.2. Executive Function in ASD

Prior (1979) was the first researcher to propose a prefrontal account of autism. The executive dysfunction account of ASD emerged mainly as an alternative explanation to the ToM hypothesis of ASD. According to this account, EF deficits are primary to ToM impairments and could potentially account for these ToM impairments in ASD as well (Pennington et al., 1997; Russell, 1997). This theoretical proposal first relied on evidence that performance on EF tasks could better distinguish between individuals with ASD and controls than ToM tasks (Ozonoff, Pennington, & Rogers, 1991) and second on results showing that performance on EF and false belief understanding measures were correlated in ASD (Ozonoff et al., 1991; Russell, et al., 1991). Cross-sectional studies on children and adolescents with ASD have revealed significant deficits in EF (see reviews of Demetriou et al., 2017 and Hill, 2004). Children with ASD show poorer performance on several aspects of EF such as working memory (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Geurts, de Vries, & van den Bergh, 2014), inhibition (Christ, Holt,White, & Green, 2007; Happé, Booth, Charlton, & Hughes, 2006), and planning (Kimhi, Kugelmas, Agam Ben Artzi, Ben Moshe, & Bauminger-Zviely, 2014; Verté, Geurts, Roeyers, Oosterlaan, & Sergeant, 2005) compared with typically developing peers. However, preserved performance has also been recorded (e.g. Hughes et al., 1994; Russell & Hill, 2001) and specific EF abilities such as inhibition of interference control (Adams et al., 2012) or the following of novel rules (Russell et al., 1999) appear to be intact in autism. Hill (2004) concludes that in order to understand the exact role of EF in ASD, studies which have carefully matched participant groups, assessments of a broad range of tasks 'fractionating the executive system' (p. 225) and which examine the patterns of impairments across development are needed. Thus, an examination of the hot and cool distinction of EF is warranted in order to further investigate the profile of intact and impaired EF abilities in ASD. Studying hot and cool EF in ASD simultaneously, could reveal whether performance in tasks across both EF domains follow a similar developmental pathway or provide further evidence regarding their internal organisation.

It should be noted at this point that although cognitive flexibility (the ability to shift between different thoughts or actions according to mutable situational demands) is another cool EF, widely studied and with deficits reported in ASD, it was decided not to include this variable in the present thesis for the following reasons:

a) Cognitive flexibility has been found to most clearly relate to repetitive behaviours in ASD (Lopez, Lincoln, Ozonoff, & Lai, 2005; South, Ozonoff, & McMahon, 2007; Yerys et al., 2009). As one of the main areas of focus of the present thesis is the investigation of the EF impact on other ASD characteristics such as social cognition/interaction deficits (i.e. ToM abilities), it was decided to put an emphasis on other cool EF skills, described in detail in the following section.

b) Due to the broad age range used in this study, the Wisconsin Card Sorting Task (WCST) would be the most suitable and age-appropriate task to measure cognitive flexibility. However, as this task includes several additional cognitive processes alongside switching (i.e. working memory, inhibition), it would not be clear whether emerging difficulties of participants were in reality because of cognitive flexibility impairments per se (Van Eylen et al., 2011).

### 1.2.3. Cool aspects of EF in ASD

#### 1.2.3.1. Planning in ASD

Planning ability has been found to be impaired in children and adolescents with ASD (Hughes, Russell, & Robbins, 1994; Ozonoff & McEvoy, 1994; Ozonoff, Pennington, & Rogers, 1991; Pellicano, 2007). Planning requires constant monitoring and (re)-evaluation of specific sequential actions in order to achieve a targeted result. Planning is relatively complex as it demands crucial decisions/choices to be made, objective approaches to be followed, as well as the implementation and revision of the plan accordingly (Hill, 2004). The Tower of Hanoi and Tower of London are two of the most commonly used tasks used to measure planning, where participants have to follow the instructions of the researcher in order to move several disks of different shapes from a prearranged sequence on three different pegs in as few moves as possible (Shallice, 1982). Studies evaluating planning ability within ASD showed that children and adolescents with ASD present impairments on tasks of this nature compared to typically developing peers (Geurts et al., 2014; Kimhi et al., 2014; Ozonoff & Jensen, 1999; Pellicano, 2007) and other clinical groups such as those with ADHD or Tourette syndrome (Bennetto et al., 1996; Ozonoff et al., 1991). In addition, the ASD group mean IQ ability fell within the normal range in all the aforementioned studies suggesting an ASD-specific deficit in planning ability which is present throughout childhood and adolescence. However, Hughes et al. (1994) suggested that it would be crucial to also investigate the effect of learning disability on the identified impairment in planning in ASD. For this reason they measured planning (using a variant of the Tower of London test, namely the "Stockings of Cambridge") in a group of children and adolescents with ASD compared to two control groups; the first group was matched according to age and learning disability and the other was matched to the verbal and nonverbal mental age (ability level) of autistic participants. Results showed that the ASD group demonstrated deficits relative to both comparison groups suggesting that it is not the influence of learning disability that causes the planning deficit. Nevertheless, the autism-specific deficit in planning was not universal across all aspects of the task used in the study. More specifically, as that task included "easy" and "difficult" puzzles to be solved, the autistic deficit was reported only in the ones labelled as "difficult". These findings suggest that children and adolescents with ASD may struggle with planning ability only at more complex levels rather than across the board. Hughes (1996) in a later study, employing a different planning task, in this case Luria's bar task, where participants have to use their planning abilities as the use of particular hand positions may lead to comfortable (target result) or awkward positions (negative result), indicated that children with ASD were impaired in their planning abilities. These results suggest that individuals with ASD may show planning deficits in a simple goal-directed motor act as well (Hill, 2004). Finally, regarding planning abilities in young children with ASD, research has shown that they demonstrate significant deficits in planning tasks relative to controls (Kimhi et al., 2014; Pellicano, 2007). Generally, it is suggested that planning is consistently found to be impaired in ASD.

#### 1.2.3.2. Inhibition in ASD

Inhibition (the ability to suppress irrelevant or no longer needed actions) is an aspect of EF related to thought and behaviour that has been widely investigated within groups of children and adolescents with ASD, in comparison to typically developing peers or peers with other neurodevelopmental disabilities (Eskes et al., 1991; Hughes & Russell, 1993; Ozonoff & Jensen, 1999; Ozonoff et al., 1994; Russell et al., 1991). Studies that have examined inhibition in ASD have provided inconsistent results due to the different measures and type of inhibition tapped. Inhibition tasks usually addressed in ASD research measure prepotent response inhibition (cancelling an initiated response) and interference control (ability to ignore irrelevant information when processing target stimuli).

Stop tasks and Go/No-Go tasks (Logan et al., 1984) are consistently categorised as prepotent response inhibition measures across the literature. This type of inhibition is usually measured with tasks that require participants to process some stimuli and respond as quickly as possible to the predominant stimuli (majority of stimuli) while suppressing a response (inhibit) to the minority of stimuli. These stimuli are traditionally signalled by the presence of particular stimuli such as a letter. Successful performance on such tasks requires participants to completely override an initiated response. A wide range of studies have demonstrated that individuals with ASD present deficits in prepotent response inhibition (Christ et al., 2007; Corbett et al., 2009; Geurts et al., 2004; Geurts & Vissers, 2011; Kilincaslan et al., 2010; Langen et al., 2011; Ozonoff & Strayer, 1997; Xiao et al., 2012). Nevertheless, several studies have reported no significant group differences between control and ASD participants for prepotent response inhibition (Chan et al., 2009; Lee et al., 2009; Ozonoff et al., 1994; Schmitz et al., 2006; Sinzig et al., 2008).

Regarding interference control, The Flanker (Eriksen & Eriksen, 1974) and Simon tasks (Simon & Wolf, 1963) are the most representative measures employed to assess resistance to distractor interference. These tasks traditionally require participants to respond to a stimulus such as a correct answer for instance, as fast as possible. Other stimuli are simultaneously shown to participants, which induce an opposite response (or a similar response) to the correct answer. The difference from prepotent response measures lies in the inhibition ability being reflected by slower responses due to the conflicting, irrelevant stimuli (Miyake & Friedman, 2012). Research has similarly indicated mixed results here as well, with some suggesting impaired interference control (Christ et al., 2011; Christ et al., 2007; Corbett et al., 2009; Yoran-Hegesh et al., 2009) and others intact (Goldberg et al., 2005; Kilincaslan et al., 2010; Larson et al., 2012; Schmitz et al., 2006; Solomon et al., 2009; Xiao et al., 2012).

Given the multifaceted nature of inhibition and the mixed results of literature, Christ et al. (2011) assessed inhibition employing several measures of inhibitory control with one cohort of participants and concluded that children with ASD present interference control deficits (assessed by the Flanker paradigm), but have intact prepotent response inhibition ability (measured with Go/No-Go task). Moreover, their findings also suggested that the reported interference control deficits may disappear with increasing age (transition from childhood to adolescence). Following Christ et al. (2011), a recent meta-analysis demonstrated significant impairments in both prepotent and interference control inhibition in children and adolescents with ASD (Geurts, van den Bergh, & Ruzanno, 2014). Results showed that performance was poorer in prepotent response inhibition suggesting that this inhibition type might be a distinct indicator of inhibitory control. As results across studies remain contradictory, more studies are needed to shed light on inhibition abilities within ASD.

#### 1.2.3.3. Working Memory in ASD

Working memory is the term used to define the system that maintains multiple pieces of transient information, and processes new or already stored information. This EF component is an important process for reasoning, learning and memory updating (Baddeley, 2003). Working memory consists of subsystems that hold and manipulate visual images (visuospatial sketch pad) or verbal information (phonological loop) as well as a central executive that coordinates them (Baddeley, 2003).

Only a handful of studies have investigated verbal working memory in ASD. Williams et al. (2005) compared the performance of children and adolescents with ASD to that of a typically developing group (matched for age, verbal, and nonverbal ability) in verbal working memory tasks and reported no deficits in the ASD group. However, two other studies (Alloway et al., 2009; Bennetto et al., 1996) that also examined verbal working memory in ASD showed that verbal working memory is impaired in individuals with ASD. Specifically, Bennetto et al.

(1996) compared a group of children with ASD to a group consisting of peers with psychiatric disorders and learning disabilities matched for gender, age and full-scale IQ (FSIQ). They found that the children with ASD showed significantly poorer performance on the complex verbal span tasks but performed equally well to peers on tasks such as forward or backward digit span tasks. Alloway et al. (2009) compared a group of children with ASD to several groups of children with developmental disorders, such as Specific Language Impairment, Developmental Coordination Disorder and Attention-Deficit/Hyperactivity Disorder and indicated that children with ASD performed significantly worse on verbal working memory tasks relative to the other groups. It should be noted though that both of these studies included only clinical populations as control groups, thus making it difficult to interpret the data as there was no comparison to standardised scores of a typically developing population. Taken together, these studies suggest that it is unclear whether verbal working memory is impaired in individuals with ASD. Thus more studies are needed in order to shed light on the verbal working memory profile in ASD.

In terms of visual working memory in ASD, research has provided mixed results. There are a number of studies suggesting that individuals with ASD present intact visual working memory (Alloway et al., 2009; Burack et al., 2009; Ozonoff & Strayer, 2001) while a series of other studies indicate that ASD groups in fact have deficits in visual working memory skills (Goldberg et al, 2005; Russell et al., 1996; Williams et al., 2005). However, the decision was taken to focus on verbal working memory in the present study rather than visual working memory as poor performance on tasks assessing verbal working memory has been found to be more strongly associated with deficits in adaptive behaviour and social difficulties in ASD (Kercood, Grskovic, Banda, & Begeske, 2014).

### 1.2.4. Hot aspects of EF

#### 1.2.4.1. Affective Decision Making in ASD

Decision making is defined as the mental processing taking place during the selection of one or more possible options in order to achieve a goal (Huitt, 1992). It usually includes the formation of preferences, the search for relevant information, and the implementation of the desired choice and the evaluation of the final result (Ernst & Paulus, 2005). Everyday decision making has been found to be impaired in individuals with ASD (Luke et al., 2012) but the results from the few studies tapping affective decision making in ASD are contradictory. Affective decision making refers to the strategic model of choice under risk where one employs both “rational” and “emotional” processes (Bracha & Brown, 2012). De Martino et al. (2008) in their study assessing affective decision making with a gambling task, indicated that ASD participants (adolescents and young adults) were inflexible and unable to employ appropriate affective cues to their decision making. Furthermore, Johnson et al. (2006) compared the performance of a group of adolescents and young adults with ASD to typically developing peers on the Iowa Gambling Task (IGT; Bechara et al., 1994) and found similar results between the two groups. However the ASD group made frequent shifts between the decks of cards that, according to Johnson et al. (2006), suggests they were less driven by the motivational significance of their choices relative to the control group. In fact, as the differences in performance between the groups were not significant, the authors concluded that probably the limited size of the sample (n=29) did not allow for the detection of significant differences. Yechiam et al. (2010) not only reported a significantly weaker performance of adolescents with ASD compared to typically developing peers during the IGT, but also that the ASD group chose new decks regardless of the outcome of the previous trial. Their study intended to investigate the frequent switching behaviour that Johnson et al. (2006) had initially demonstrated. They suggested that this decision making style was driven by the ASD participants’ desire to explore new choices, and not by the motivational cues from the previous outcomes. Therefore, based on these results they proposed a new cognitive model of making choices in IGT, according to which, individuals with ASD would choose decks influenced by the exploratory value of the response option, rather than the motivational or emotional significance the outcome value might have to them. Regarding middle childhood, very little is known about affective decision making in ASD, with one study (South et al., 2014) suggesting that children (mean 11 years) with ASD demonstrated significantly better performance on the IGT than controls and another (Faja et al., 2013) reporting comparable performance of younger children with ASD (6-7 years) to the control group on the Children’s Gambling task (Kerr, & Zelazo, 2004).

Another study examining affective decision making in ASD (South et al., 2011) focused on the risk taking ability of children and adolescents with ASD. Risk taking refers to the tendency to get involved in harmful or dangerous behaviours which provide at the same time the potential for a positive outcome (Kogan & Wallach, 1964). The task used in that study, the Balloon Analogue Risk Task (Lejuez et al., 2002) required the participants to pump up a virtual balloon without making it burst. The participants earned a point for each successful attempt. Therefore, risk taking was measured by the number of pumps that participants gave to the balloon. There were no significant differences between the two groups; however, the ASD group demonstrated an increase in their risk taking scores as their levels of anxiety increased. The researchers suggested that risk taking in ASD may be motivated by a fear of failure, while in typical development it is driven by sensitivity to rewards. However, as this study involved risk taking in relation to anxiety levels, it can be argued that it would be difficult to know whether this specific manifestation of risk taking in ASD is an autism effect or a product of higher anxiety overall.

Taken together, this evidence suggests that individuals with ASD employ a different strategy to gambling tasks than typically developing peers, as they may not rely on the internal affective values to make their decisions. In other words, there seems to be a disconnection between affect and cognition in individuals with ASD that results in deficits in decision making ability. To date, research examining affective decision making in ASD has been carried out only with limited samples of adults or older adolescents and little is known about these processes in school-aged children. The present thesis aims to address this gap in the literature.

#### 1.2.4.2. Delay Discounting in ASD

Delay of gratification and delay discounting reflect two similar indices of impulsivity that are very often treated as if they represent the same construct. Delay of gratification refers to the ability to control one's temptation to obtain an immediate reward and wait instead for a later reward (Carducci, 2009). Delay of gratification is usually used in early childhood as in its most common procedures, primary reinforcers such as food or objects of interest are used. In delay of gratification tasks children are sat at a table opposite the researcher and then presented with a choice between a more preferred or larger reward (e.g. two cookies) and a less preferred or smaller reward (one cookie) (e.g. Mischel & Baker, 1975). When children make their choice, they are explicitly instructed that they will obtain the preferred reward once the researcher is back in the room with them (the delay does not last more than 15 to 20 minutes) or that they can have the less preferred reward immediately or at any time during that delay if they ring a bell. Of course if children do not control their impulsivity and take the less preferred reward, they do not have the right to receive the initially preferred delayed reward. In contrast to delay gratification, delay discounting procedures focus more on "initial-choice responses" (Reynolds

& Schiffbauer, 2005). These procedures typically present choices between larger delayed and smaller but more immediate monetary rewards. When participants choose one option, they are committed to that until the next choice trial; in other words, as Reynolds and Schiffbauer (2005, p. 443) state: “there is no requirement to sustain a choice in that there is no opportunity to defect to the more immediate option after having made a choice for the delayed reward”. Tasks tapping delay discounting have used both hypothetical and real rewards as well as a variety of delay intervals (Johnson & Bickel, 2002; Scheres, Sumiya & Thoeny, 2010). Delay discounting was studied in the present thesis as it is apparent that delay of gratification tasks can only be used with young children in nursery or reception due to ceiling effects yielded with older children or adolescents (i.e. the nature of its structure and reinforcers) (Wilson, Andrews, & Shum, 2017).

To date, there have been no studies which have investigated delay discounting exclusively in individuals with ASD. However, a limited number of studies have examined delay discounting in children and adolescents with ADHD relative to ASD and typically developing peers (Antrop et al., 2006; Chantiluke et al., 2014; Demurie et al., 2012). More specifically, ADHD and ASD share common deficits in cool EF, such as inhibition, planning and working memory (Leitner, 2014) as well as shared deficits in the hot aspects involving decision making (reward related), reward processing, and temporal (delay) discounting (Noreika et al., 2013; Scheres et al., 2008). In general terms, children with ASD have been found to be impaired in motivational processing (Berger, 2006) and in forming rules when they are involved in stimulus-reward associations (Dawson et al., 2001). Although these reward-related deficits are suggested to be implicated in ASD, there is no evidence that they are related to delayed rewards as well. Antrop et al. (2006) reported no differences in the performance of children with ASD compared to typically developing peers in tasks assessing choices for either small, instant rewards or large, delayed rewards. In their study, children with ASD were compared to both an ADHD group and control group with the researchers stating that deficits were demonstrated only in the ADHD group. Demurie et al. (2012), in line with Antrop et al. (2006), suggested that it was children with ADHD, but not children with ASD, who preferred to choose small immediate rewards instead of large delayed rewards significantly more frequently than the control group. Taken together, these studies suggest that children and adolescents with ASD cannot be considered as delay averse. However, a functional magnetic resonance imaging (fMRI) study recently conducted by Chantiluke et al. (2014) investigating the differences in delay discounting and the underlying correlations of brain-behaviour in

ADHD and ASD presented contradictory results. Specifically, they found that only the ASD group showed significantly poorer discounting ability compared to the control group. Thus, results show that more light needs to be shed on delay discounting ability within the autism spectrum as there is little knowledge about the delay discounting patterns followed in ASD.

The hot and cool EF distinction model, incorporating affective and emotional elements that typically work together as part of a more general adaptive function (Zelazo & Carlson, 2012) will be used in the present study as it has been proposed to shed more light on the roles of specific EF in clinical populations. As presented above, EF deficits are significant across age in ASD with Zelazo and Müller (2002) suggesting that ASD may be primarily impaired in hot EF with secondary impairments in cool EF. Cool EF has indeed been found more associated to children's cognitive and academic achievement (Willoughby et al., 2011), whereas hot EF has been found to be more implicated in children's disruptive social behaviour (Garner & Waajid, 2012). As the clinical profile of ASD is mostly characterised by disruptive social behaviour, it would be critical to explore the role of hot EF in ASD's behavioural outcomes under such a theoretical perspective. Research on EF deficits in ASD has mainly focused on cool EF aspects, failing to integrate the hot EF processes. Adopting a fractionated approach, could shed more light on the neurodevelopmental profiles of intact and impaired EF abilities in ASD. Moreover, as research on hot EF is relatively scarce in middle childhood and early adolescence, the present study will attempt to explore the group differences in both cool and hot EF simultaneously addressing the age gap in the literature. No study to date has investigated hot and cool EF simultaneously in the ASD population.

### 1.3. Development of Executive Function

There was a dramatic increase in the interest regarding the development of EF over the last decade, as clearly indicated by the fivefold increase in the number of published studies on this topic (Carlson, Zelazo, & Faja, 2013). Recent research is paying more attention in EF development because individual differences in EF have been found to be crucial in understanding children's development (Brock et al. 2009), particularly in predicting important developmental outcomes. Furthermore, there is an increasing number of studies as well (outlined in the following sections) indicating that different EF aspects present differentiated trends in their developmental pathways and reach performance maturity at different ages during childhood and adolescence. However this research presents several limitations that account for difficulties in the construction of a truly developmental account of EF. More specifically, the vast majority of research has focused on limited age ranges (e.g. 2-5 years) (Isquith et al., 2004) and especially on pre-schoolers (Garon et al., 2008). A possible explanation lies in the rapid improvements in the performance on EF tasks which occur throughout the preschool period and early years of primary school (Carlson & Moses, 2001). Furthermore, there is limited knowledge about the developmental processes occurring after the age of 5 years, especially when children make the transition from childhood to adolescence. The purpose of the following section of this chapter is to set the basis for the construction of such a developmental account, first in relation to typical development, followed by the empirical research about the developmental pathway of EF found in ASD. The present thesis thus focuses on the few studies that have included a broad age range aiming to describe the developmental trajectories during childhood and adolescence of EF in both typical development and ASD.

As already mentioned, EF has been suggested as being regulated by the prefrontal cortex. Evidence from imaging studies has indicated that the development of the prefrontal cortex, like brain development in general, includes both progressive (e.g. myelination, neuron proliferation) and regressive changes (e.g. cell death, pruning of synapses) (O'Hare et al., 2008). The maturation of the prefrontal cortex occurs in adolescence, as researchers have found a further loss of gray matter during this period (O'Hare et al., 2008) in contradiction to other brain structures that present an early maturation (e.g. the brain areas underlying speech/language development). O'Hare and Sowell (2008) mention that during this period the aforementioned progressive and regressive changes take place simultaneously and are certainly influenced by the child's experiences and stimulation provided (Best & Miller, 2010). Generally, research on the development of EF has indicated that the emergence of EF occurs in the early years of life, followed by critical changes throughout the preschool era. Zelazo et al. (2008) though, demonstrated that it continues to develop at least during the adolescence protracted to the development of the prefrontal cortex.

Developmental studies using standard neuropsychological tasks have shown that EF has a protracted course of development, beginning in early childhood and continuing into adolescence. However, these EF tasks are subject to distinct developmental trajectories. Traditionally, the development of EF has been investigated mainly using tasks tapping only the cool aspects of EF which lack significant affective or emotional components. Thus, little is known about the developmental trajectories of hot EF processes during early and later childhood. The following section of this chapter will present the most up to date research outcomes relating to the developmental trajectories of EF in typical development across time and age, distinguishing between hot and cool aspects, followed by the relevant literature of ASD trajectories.

### 1.3.1. Development of Cool Executive Function

#### 1.3.1.1. Development of Inhibition

In typical development, inhibition starts developing during infancy with Garon et al. (2008) suggesting that rapid improvements occur in early childhood on several inhibition tasks. For example, for Luria's Hand game where children are required to demonstrate a fist when a finger is showed and vice versa, the most improvement is recorded between the ages of 3 and 4 years (Carlson, 2005), whereas in more demanding tasks such as the Day/Night task improvements continue even into middle childhood (Gerstadt et al., 1994).

Findings regarding later improvements in inhibition, especially after the age of 5 years are mixed and not consistent. Klenberg et al. (2001) examined a wide age range and reported improvements from the age of 3 to 6 years on inhibition tasks such as the Knock and Tap game (similar to Luria's game; tap when the researcher knocks and vice versa). However, in the same study no further significant improvements were found through to the age of 12 years. It should be noted though, that the tasks employed in this study were probably relatively easy for the older children. In line with the notion that inhibition ability is established during the early years, the study of Lehto et al. (2003) reported no significant changes between the ages of 8 and 13 years.

On the other hand, a few studies have demonstrated developmental changes in inhibition after the 8th year. Interestingly, the majority of these studies have used computerised tasks such as the Go/No Go paradigm which require a response to specific stimuli and response inhibition to another (Cragg & Nation, 2008; Jonkman et al., 2003; Lamm et al., 2006). Results show significant changes from 7 to 11 years on behavioural measures tapping factors such as "disinhibition" (labelled by the authors) (Brocki & Bohlin, 2004) as well as significant decreases in commission errors (score indicating the number of times the participant responded but no target was presented) between 9 years and adulthood (Jonkman et al., 2003). Furthermore, Johnstone et al. (2007) found that the performance on a Stop-Signal task was sensitive to changes across 7 and 12 years. Finally, Huizinga et al. (2006) found continued improvement on inhibition measures such as the Stop-Signal until the age of 15 years, and of 21 years on Stroop-like tasks. Taken together, it is suggested that performance on inhibition tasks may improve even beyond early childhood contradicting the notion that performance on these tasks matures early on.

In summary, regarding the developmental pattern of inhibition ability within typical populations, it is suggested that the rapid improvements between 3 and 5 years of age are followed by less dramatic changes between 5 and 8 years and even slower alterations in adolescence. There is no evidence so far about the type/pattern of the developmental trajectory from age 3 to adolescence, whether it is linear or quadratic for instance, in part as it has been difficult to find appropriate tasks that could assess inhibition across such a large age span.

#### 1.3.1.2. Development of Working Memory

The extensive review of Garon et al. (2008) regarding the development of EF aspects on the preschool age, mentions that various tasks record improvements in working memory ability during the preschool years. The development of the neural circuitry underlying working memory exhibits both progressive and regressive changes similar to the neural mechanism of inhibition (Best & Miller, 2010). Specifically, Gathercole et al. (2004) found that working memory is adequately developed by the age of 6 years and even used in complex tasks in which the coordination of working memory subcomponents is required (e.g. coordination of visual and verbal working memory). In addition, the same researchers showed that both “easy” and “demanding” working memory tests followed similar developmental trajectories; that is to say a linear increase was observed from age 4 to 14 years and a levelling off between 14 and 15 years across almost all tasks tapping this aspect of EF (Best & Miller, 2010).

Studies using non-verbal working memory tasks such as spatial working memory have shown that the performance of participants remained similar between 9 and 20 years (Luciana et al., 2005) while results from experiments addressing visuospatial tasks indicated that performance continued to improve until 16 years of age (Conklin et al., 2007). With regards to verbal working memory tasks, Best and Miller (2010) state that the developmental trajectory is similar to that of visuospatial working memory ability. However, as Best and Miller (2010) mention, when tasks requiring the maintenance and manipulation of multiple items were employed (Luciana & Nelson, 1998) maturity was reported only in adolescence which suggests that the development of working memory occurs gradually through adolescence, especially for complex and demanding tasks. In summary, this evidence indicates that the developmental trajectory of working memory ability is suggested to be linear from preschool age to adolescence.

#### 1.3.1.3. Development of Planning

Planning is a relatively complex cognitive construct that is suggested to rely on a specific interaction between working memory and inhibition. As already described above, although there is evidence that inhibition and working memory emerge in early childhood (subsequently planning ability as well) and continue to develop through adolescence, it is not yet clear when planning reaches maturation levels (Asato et al., 2006). In fact, Atance and O'Neill (2001) suggest that planning emerges by the age of 2 years and becomes more robust during the preschool years, but is not well developed until 4 years of age. Several studies, through involving broad age ranges, have demonstrated that planning skills, as measured by the Tower of London task, improve throughout adolescence (Albert & Steinberg, 2011; Asato et al., 2006; Huizinga et al., 2006).

One of the largest studies examining age differences in planning skills was that of Korkman et al. (2001) which used the Tower of London task with 800 typically-developing children aged between 5 and 12 years. The researchers found significant developmental changes through middle and late childhood; however as this study lacked an adolescent comparison group, the developmental maturity point could not be identified. Huizinga et al. (2006), in their study employing the Tower of London task with a broad age range (7 years until late adolescence), found that the number of errors made continued to decrease from middle childhood until young adulthood. Asato et al. (2006) presented similar results in their study measuring planning with the Tower of London task with participants aged between 8 and 30 years, as they reported an increasing performance on the complex parts of the task with age. The performance on planning measures is suggested to reach a plateau between the ages of 15 and 30 years (Anderson et al., 2001; De Luca et al., 2003). In line with previous research, Albert and Steinberg (2011) also found that performance on the Tower of London task improves across adolescence. Finally, de Luca et al. (2003) also employing the same task suggested that the performance trajectory followed a pattern of steady improvement with the age of 12 to be the age point of effective planning skills. The older group in that study (11-14 years) presented performance gains as they solved significantly more successful trials than the young group (8 years old). This evidence suggests that planning ability trajectory presents age-related improvement across adolescence.

### 1.3.2. Development of Hot Executive Function

Research investigating the functional implications caused by changes in the neural structures underpinning EF has focused almost exclusively on the dorsolateral prefrontal cortex and cool EF. More light needs to be shed on the development of hot EF although there is some evidence that the underpinning neural mechanism, the ventromedial prefrontal cortex, is developed earlier than the dorsolateral prefrontal cortex (Gogtay et al., 2004).

There has been very little research to date examining developmental changes in hot aspects of EF, not only in the early years of life, but during later childhood and adolescence as well. Generally, it is suggested that hot EF follows a rapid development during the preschool years in typical development (Zelazo & Müller, 2002) and that age-related improvements are demonstrated during middle childhood and adolescence (Prencipe et al., 2011). Only a few cross-sectional studies to date have investigated the development of hot EF (in conjunction with cool EF) mainly in typical development and have yielded mixed results. No significant differences have been found in the development of hot and cool EF in the preschool period (3-5 years) with both domains being correlated and exhibiting performance gains after the third year of life (Hongwanishkul et al., 2005). Further evidence from middle childhood and adolescence (Hooper et al., 2004; Prencipe et al., 2011) suggested that the weakly correlated hot and cool EF develop independently, and hot EF is likely to follow a differentiated developmental trajectory beyond the 5 years of age. The present thesis will thus attempt to investigate the nature of the relationship between cool and hot EF aspects in both typical development and ASD.

#### 1.3.2.1. Development of Affective decision making and Delay discounting ability

Carlson, Davis and Leach (2005) conducted a study on the development of children's affective decision making using a reverse contingency task. Children (3 and 4 years old) were told they could win a large reward only if they pointed to a smaller reward first. Instructions explicitly stated that the chosen treat would be given away and they would get to keep the other one. The younger children, but not the older children, exhibited difficulties in pointing to the smaller object rather than the bigger one. However, when the researchers decreased the motivational value of the task by using symbols instead of treats, the performance of the youngest children improved. Prencipe et al. (2011) report that these results suggest that the affective element of the task (the presence of rewards) interferes with the children's ability to implement the top-down control (the ability to control one's cognitive processes) required in this assessment.

In another study (Hooper et al., 2004) assessing hot and cool EF in typically developing children and adolescents (aged 9-17 years), hot EF (affective decision making) was measured using the gambling task (Bechara et al., 1994). The researchers found age-related improvements in the performance trajectories on every EF tasks but whereas improvements on the cool EF tasks (Go/No-Go and Digit Span) were found between the two youngest age groups (9-11, 11-13 years), only the older adolescents (14-17 years) performed well on the gambling task. Cool and hot EF were also weakly and marginally significantly related. In other words, these results suggest that hot EF may follow a different, delayed developmental trajectory in comparison to cool EF.

Prencipe and Zelazo (2005) assessed delay discounting ability in young children who were told that they could choose either a simple single treat immediately or more than one treat at the end of the game. Results showed that the younger children (3 years old) were less able to delay the rewards compared to the older ones (4 years). Furthermore, Steinberg et al. (2009) employed a delay discounting task with younger and older adolescents in which participants had to choose between a smaller reward received immediately and a larger one delayed until the end of the assessment. They found that the younger adolescents (<16 years) presented a steeper trajectory in their tendency to discount delay reward, suggesting they were less able to delay the reward, relative to older adolescents or adults.

Prencipe et al. (2011) examined the development of both hot and cool EF from middle childhood until later adolescence. It was found that performance on all tasks significantly improved with age; however the developmental changes of the cool EF tasks occurred earlier and were considered more robust as well (in terms of the statistical results). In terms of hot EF though, some improvements were reported only among the oldest group (14-15 years old). Specifically, results relating to performance on the gambling task showed that only the oldest adolescents performed better by the second half of the test, as well as for the delay discounting in which the impulsive choices were gradually decreased only across the oldest participants (14-15 years).

Research on the developmental trajectories of EF has been mainly descriptive, focusing on the threshold ages at which the different EF aspects emerge, age points of rapid improvements and peak maturity. However, research needs to move towards addressing issues of developmental mechanisms. Specifically, it is necessary to shed more light on those mechanisms underlying children's transition from early to later levels of competence within EF subcomponents and to investigate whether the early phase of the development of one EF aspect facilitates the developmental process of other EF aspects. The comparison of different trajectories of several EF components could reveal patterns and mechanisms of development as it may identify a neuropsychological model derived from in-detail, fractionated brain-based profiles of development. Thus, the developmental relationships among EF components could be examined in studies designed to include testing of several EF components simultaneously and across different age ranges. The present thesis will address several EF developmental trajectories in an attempt to establish such a comparison in middle childhood and adolescence.

### 1.3.3. Development of EF in ASD

EF in typical development continues to develop towards maturation until middle and even late adolescence as already described above, suggesting an extensive plasticity of the underpinning neural structure (Luna & Sweeney, 2004). It is unclear whether the trajectory of EF in ASD is similar to that identified in typical development. With the executive deficits persisting in ASD, it is of great importance to thoroughly investigate the developmental trajectories of EF in children and adolescents with ASD in order to overcome the limitations of the current cognitive models and facilitate the development of efficient interventions to improve the everyday lives of individuals with ASD. In general terms, studying and examining in depth the underlying pathology of developmental disorders such as ASD, especially during childhood or adolescence, provides researchers with the opportunity to identify potentially disrupted cognitive processes that may contribute to new diagnostic standards as well as new treatment and intervention strategies (Sonuga-Barke & Halperin, 2010). One of the main questions that needs to be addressed in ASD research is whether the EF deficits in children and adolescents with ASD simply represent a delay in brain maturation or should be considered as a thorough deviation from typical development. Thus, the present thesis will attempt to provide a baseline to answer this question.

**Executive Function in ASD: "Lack of cognitive development or delayed development? Is impairment constant throughout development?"**

The investigation of the developmental trajectories of EF in a broad age range within ASD could reveal information of great importance about the emergence and/or expression of this cognitive construct. More specifically, if the impairment emerges only in the early development of children with ASD, this would automatically imply that there is a developmental delay in terms of EF and that the maturation processes such as myelination or pruning combined with the stimuli from the environment compensate for the original deficit. If, however, the EF impairments are present only later in development, it might suggest that children with ASD have deficits in their developmental transition to adolescence with the brain maturation processes probably impaired. Finally, if the deficits of EF persist throughout development, it could mean that these impairments are not caused by the damaged brain maturation processes thus implying intact developmental mechanisms and existing plasticity. A potential clarification of the nature of executive dysfunction in ASD through the present thesis will shed light on mechanisms of development and its implications for intervention. Employing the model of distinguishing between hot and cool aspects of EF is warranted in order to profoundly "fractionate" the executive system and to provide a solid ground towards a clearer definition as well of the patterns of impairments across the children's development. There is no study to date having investigated the developmental trajectories of hot and cool EF simultaneously in ASD.

### 1.3.4. Development of cool and hot EF in ASD

Researchers have devoted little attention to the investigation of the age-related changes in EF in ASD. Research examining EF in ASD at several age points have presented mixed results. Although the studies conducted on samples of adolescents or adults have yielded consistent results, evidence from research using younger ages such as preschool children is inconsistent. Specifically McEvoy et al., (1993), using a spatial reversal task in young children with ASD (mean 5 years old), found deficits in EF (in the aspect of shifting) relative to the control groups (children with delayed development of similar non-verbal mental age and normally developing children of similar verbal IQ). In contrast, in the study of Wehner and Rogers (1994) who addressed a similar task tapping shifting attention on a group of preschoolers (mean 3.5 years old), no evidence of executive impairments was revealed. In fact, several studies employing tasks of cool EF such as A-Not-B, Spatial Reversal, and the Windows task, in very young children have found that the performance differences between the typically developing and the ASD group were not significant (Griffith, Pennington, Wehner, & Rogers, 1999; Rutherford & Rogers, 2003; Yerys, Hepburn, Pennington, & Rogers, 2007). This suggests that selective EF in ASD during the early years of life may be similar to the EF profile of the typically developing peers.

As it has already been described, the developmental theory of EF suggests that generally EF emerges in the early years of life (Diamond, 2006) and demonstrates a maturation spurt in late childhood and preadolescence (Luna et al., 2004) with adult levels of performance usually reached by 12 years of age (Zelazo et al., 2003). This developmental framework could provide an explanation for the inconsistencies found in the EF skills of individuals with ASD at various age points. More specifically, the aforementioned lack of executive dysfunction in young pre-schoolers with ASD could suggest that initially EF in ASD may follow a similar developmental pathway as in typical development. With regards to the investigation of the developmental pathway of EF in older children and adolescents with ASD, longitudinal and cross-sectional studies have yielded significant evidence but mixed results (Luna et al., 2007; Ozonoff & McEvoy, 1994; Pellicano, 2010). Generally very few studies have compared the performance of different EF processes in younger and older participants with ASD.

Ozonoff and McEvoy (1994) employed measures of EF (i.e. tasks of planning and cognitive flexibility) with a group of children and adolescents with ASD compared to a learning-disabled control group first at age 12 years and then at 15 years of age (3 year follow up study). They found that the ASD group demonstrated significantly poorer performance on the relevant EF tasks, which also appeared to reach a developmental ceiling compared to the group with the learning disabilities. In addition, results also showed that the ASD group improved very little across time suggesting a lack of age-related improvements. Griffith, Pennington, Wehner, and Rogers (1999) reported similar findings to Ozonoff and McEvoy (1994). Pre-schoolers with ASD (mean 4.3 years old) followed up after one year did not present any age-related improvements on a task of cognitive flexibility. Luna et al. (2007) used a cross-sectional design with three age samples (8-12 years, 13-17 years, 18-33 years) in order to examine performance on an antisaccade task of response inhibition. In this kind of inhibition measure, participants are asked to fixate on a motionless target followed by a stimulus presented to one side of the target. Participants are then asked to make a saccade towards the opposite direction of the stimulus (i.e. stimulus is presented to the left of the motionless target, the patient should look toward the right). Failure to inhibit a reflexive saccade is considered as an error to this task. In contrast to evidence from other studies indicating intact inhibitory control in ASD (Ozonoff et al., 2004; Ozonoff & Jensen, 1999; Ozonoff & Strayer, 1997), Luna et al. (2007) reported deficits in inhibition for the ASD group that persisted across development. Happé, Booth, Charlton, and Hughes (2006) compared a group with ASD to a group of individuals with ADHD and a control group of typically developing peers across middle childhood and adolescence (8-11 years, 11-16 years) using a variety of EF tasks tapping aspects of response inhibition, planning, working memory and cognitive flexibility. They found that both the older typically developing group and the older ASD group, performed significantly better than the younger ones on several EF such as response inhibition and working memory. On the other hand, the participants in the ADHD group did not demonstrate any age-related differences in performance. Researchers thus suggested that EF deficits may improve with age in individuals with high functioning ASD. Another study including participants with ASD in a broad age range (6-47 years) was that by Ozonoff et al. (2004) which assessed shifting attention and planning abilities. Their results showed that there was no significant correlation between age and performance on the EF tasks that were employed, consistent with the results presented in the original study by Ozonoff and McEvoy (1994) who found no age related improvements. Another study (Pellicano, 2010) examining the developmental course of EF in ASD, followed children with ASD (mean age 5.5 years) for 3 years and measured EF aspects such as set shifting and planning. Pellicano showed that children's ability in planning improved significantly over the 3 year period, surprisingly at a faster rate than the typically developing children of the comparison group. Her results are contradictory to those of the other two longitudinal studies on EF in ASD already described which reported no age-related improvements in both the young group or the adolescent groups with ASD (Griffith et al., 1999; Ozonoff & McEvoy, 1994). These inconsistencies could be explained in relation to potential differences, in task or sample selection since the first two studies for instance included less able participants with ASD than the high functioning participants included in Pellicano's study (2010). Finally, a recent developmental EF study in ASD examined the effect of age in children and adolescents with ASD aged between 8-18 years old (van Eylen et al., 2015). Participants were assessed in measures of EF such as inhibition, cognitive flexibility, working memory and planning. Results showed that generally increasing age was related to higher scores on the tasks measuring inhibition, flexibility and working memory suggesting that EF is characterised by age-related improvements across childhood and adolescence in ASD.

In sum, taken together, these studies show there is no clear developmental framework of EF in ASD due to inconsistent results; with some reporting age-related improvements in ASD and others not. In addition, there may be different developmental patterns for different aspects of EF. The findings, especially from longitudinal studies, indicate that there are mainly few changes in EF across time in ASD, suggesting that there is probably a developmental ceiling for these abilities in individuals with ASD. However, there is no study to date having investigated the development of hot EF in ASD. The present study will shed more clarity on the pattern of the EF trajectory within the ASD, by addressing tasks of both cool and hot EF skills, in an attempt to fully grasp the EF developmental deficits of individuals with ASD in middle childhood and adolescence.

### 1.4. "Real-Life" Executive Function

The variability in the investigation of EF and its developmental trajectories, is significantly impacted by the complex and multifaceted nature of EF as a construct. Based on the theoretical background described earlier, EF is suggested as a set of domain general cognitive processes tapped by a wide range of different cognitive tasks. Potential differences in operational designs, and modality of assessment often make the comparison and interpretation of results complicated, while other contextual variables may in reality influence EF performance. These concerns are part of the criticism regarding the highly structured research environments of laboratory settings in EF examination. The investigation of the executive difficulties in ASD and their development across age are argued to heavily rely mainly on laboratory experimental measures that do not capture the behavioural difficulties of everyday life (Liss et al., 2001). Thus, a question of "ecological" validity has been addressed by several investigators who have suggested the use of measures that capture the functioning of children with ASD in everyday settings simulating real-world demands (Manly, Robertson, Anderson, & Nimmo-Smith, 1999). Although "real-life" environments may also be affected by the same methodological issues as the performance-based tasks, they are not likely to scaffold EF performance (Wallace, Yerys, Peng, Dlugi, Anthony, & Kenworthy, 2016) and may reveal EF deficits or subtle developmental changes not identified in laboratory settings. The most widely used “real-life” (ecologically valid) EF measure to date is the Behavior Rating Inventory of Executive Function (BRIEF), a rating scale assessing the emerging EF problems in everyday life either in school or at home (Gioia, Isquith, Guy, & Kenworthy, 2000). BRIEF is highly sensitive in detecting EF deficits among pre-schoolers (McLean et al., 2014), school-aged children (Blijd-Hoogewys, Bezemer, van Geert, 2014; Leung, Vogan, Powell, Anagnostou, & Taylor, 2016; Panerai, Tasca, Ferri, D’Arrigo, & Elia, 2014) and adults (Wallace, Kenworthy, Pugliese, Popal, White, Brodsky, & Martin, 2016). The weak or non-significant correlations between performance-based EF (lab settings) tasks and parent/teacher ratings on EF scales such as the BRIEF (e.g. Mackinlay, Charman, & Karmiloff-Smith, 2006) provide evidence not only for the independency of these different measures but also theories suggesting that they tap different cognitive constructs (Toplak et al., 2013). Their separable and complementary contributions to the broader understanding of the multifaceted nature of EF is warranted and necessary when planning interventional cognitive or behavioural studies in typical development and ASD.

The investigation of the development of “real-life” EF using ecologically valid tools such as the BRIEF became a reality only in recent years. Huizinga and Smidts (2010) were among the first to investigate the age-related differences in “real-life” EF in a large sample of typically developing children (5-18 years), using the BRIEF rating scale. BRIEF focuses on two areas of EF, namely behavioural regulation and metacognition. Behavioural regulation refers to the capability of shifting and controlling emotions whereas metacognition is defined as the ability to monitor performance and self-manage tasks (Huizinga & Smidts, 2010). For instance, some of its items include questions such as “Has trouble with chores or tasks that have more than one step” or “Becomes overwhelmed by large assignments”. Psychometrics and clinical utility of the BRIEF are discussed in more detail in Chapter 2. Results showed that children and adolescents ($n= 847$) presented differentiated developmental patterns in the main four EF domains of BRIEF: working memory and shift presented developmental improvements only before adolescence (< 11 years) while inhibition appeared to develop until young adulthood (18 years). No age-related changes were found in terms of planning. The evidence of the extended development of inhibition was in line with findings from previous studies with performance-based EF measures in contrast to the reported developmental pattern of working memory, shift and planning abilities that appeared to be different (van den Bergh et al., 2014). More specifically, developmental gains of planning and working memory as tapped by EF laboratory measures seem to be present not only in childhood but adolescence too, suggesting that EF rating scales such as the BRIEF and performance-based tasks may actually follow differentiated pathways in typical development.

Relevant examinations of “real-life” EF developmental trends in ASD are rather limited. Following Huizinga and Smidts (2010), Rosenthal et al. (2013) investigated the development of BRIEF subscales (working memory, inhibition, shift, and planning) in children and adolescents with ASD (5-18 years old). Their results showed that working memory performance was poorer in older participants (14-18 years) compared to the younger ones (6-7 years) implying that deficits on working memory increase in adolescents with ASD as reported by parents. No age-related improvements were found in the remaining subscales. In a similar developmental study with children and adolescents with ASD (6-18 years), using the same BRIEF subscales (inhibition, shift, working memory, and planning), van den Bergh et al., (2014) found that inhibition presented age-related improvements while planning deficits were more evident in older participants relative to younger ones. No age-related improvements were found in working memory of children and adolescents with ASD. “Real-life” EF (as tapped by the BRIEF) in ASD (particularly metacognitive abilities) may not improve at the same rate as performance-based tasks assessing EF abilities in childhood and adolescence in ASD.

The present study will investigate teacher-reported “real-life” EF abilities (BRIEF scale) of children and adolescents with ASD focusing on age-related differences, as the research conducted in this area is limited and has yielded mixed results. A special focus will be turned on comparing the developmental trends of these “real-life” EF abilities with those of performance-based EF skills, in order to shed more light on the relation between these two different types of EF measures.

### 1.5. The relationship between Executive Function and Theory of Mind

ToM is the capacity to understand another's perspective or mental state and subsequently respond with an appropriate emotion to that mental state (Rogers et al., 2007). ToM enables us to engage in complex, yet fluid social interactions. The most crucial abilities of ToM have been found to develop during the early years of development, although several studies have demonstrated that its maturation extends into older childhood (Flavell, 1999). Recent studies have actually suggested that the maturation of ToM continues until adolescence and even into young adulthood (Apperly et al., 2008; Dumontheil et al., 2010)

Several studies have reported strong associations and that the development of ToM is dependent on EF (Best, Miller, & Jones, 2009; Carlson, Moses, & Claxton, 2004; Frye, 2000; Hughes & Ensor, 2007). Carlson et al. (2002) posit that there are specific domains of EF, such as inhibitory control and working memory, considered to be predictive of the emergence and evolution of ToM in early childhood. Typically developing children's EF abilities (e.g. inhibitory control and working memory) have indeed been found to be significantly correlated with ToM in early childhood (3-4 years) (Carlson, Moses, & Breton, 2002; Carlson & Moses, 2001; Devine, White, Ensor, & Hughes, 2016; Hala, Hug, & Henderson, 2003; Hughes, 1998a). Individuals need inhibitory control when they process other people's mental states/perspectives, as the inhibition of their personal perspective allows them to consider other people's feelings or thoughts (Birch & Bloom, 2004). Moreover, working memory could allow the simultaneous active processing in the mind of both one's own and another's perspective. More specifically Moses and Carlson (2004, p.135) highlight that "effective social cognition is not possible unless one is able to hold in mind relevant perspectives (working memory) and to suppress irrelevant ones (inhibition)." Further support for the strong relations between these two cognitive domains was provided by studies having shown that EF was related to a ToM false belief explanation task even when its inhibitory demands were reduced for example (Moses & Carlson, 2004; Perner, Lang, & Kloo, 2002).

The EF-ToM association is thought to be more than skin deep as both abilities are suspected to be fundamentally linked across development for several reasons (Carlson, Claxton, & Moses, 2013). Starting with early childhood, it has been noticed that when pre-schoolers face difficulties understanding or inferring mental states in ToM false belief tasks, self-control problems such as retaining attention and controlling impulsivity, occur simultaneously. Furthermore, both abilities are suggested as following joint developmental trajectories and parallel developmental timetables of substantial growth (Kochanska, Coy, & Murray, 2001). From a neurological perspective, ToM and EF have been found to rely on common neural structures with specific areas of the frontal lobes activated for different measures tapping each ability (Gallagher & Frith, 2003). Moreover, extending the investigation of this interrelation in clinical populations has shown that for example impairments in specific abilities of EF and ToM are both involved in the ASD phenotype (Ozonoff, Pennington, & Rogers, 1991). Finally, according to the expression account of the EF-ToM relation (Moses, 2001), successful performance in ToM mental states reasoning would require some level of self-regulation (EF). More specifically, if young children exhibit poor self-regulation, they are very likely not to inhibit their personal beliefs in order to infer another's emotional state for example. Thus EF impairments are likely to account for children's difficulties in ToM tasks (Moses, 2001). Moses's proposition is consistent with Russell's (1996) theoretical account of ToM emergence stating that children must first acquire self-regulation efficacy that will allow them to disengage from the salient, misleading stimuli or inhibit their personal reflections of events before formulating successful others' mental states. In contrast with Russell's theory of EF being essentially a prerequisite for ToM development, Perner (1998) and Perner and Lang (1999) have proposed a theoretical conceptualisation that considers ToM to give rise to the development of EF. Perner suggests that ToM is the ability to be obtained first before children can regulate and control themselves. A third theoretical view (Frye, 2000; Frye, Zelazo, & Burack, 1998) on the EF-ToM relation posits that there is a crucial cognitive ability of the preschool period, namely the reasoning about complex problems involving attention, which develops first and then provides a platform for successful performance on both EF and ToM tasks. However, results from longitudinal studies on the EF-ToM relationship in early childhood in typical development to date have shown that young children's early performance on EF measures (T1) is a significant predictor of the ToM false belief later performance (T2) (independent of age, verbal ability, and earlier ToM scores) but not vice versa (Carlson et al., 2004; Flynn, 2007; Hughes & Ensor, 2007). This evidence underlines that EF seems to be a crucial prerequisite for the development of ToM in early life at least, as it may scaffold the emergence of ToM mechanisms (Apperly, Samson, & Humphreys, 2009).

The vast majority of research on the development of ToM and the interrelation with EF trajectory has focused exclusively on the preschool period. However, it is essential that research focuses on older children and adolescents for several reasons. Specifically, middle childhood and adolescence are two developmental stages of great interest as the brain undergoes dramatic structural and functional changes in its neural mechanisms (for instance in the frontal, parietal, and temporal cortical regions) (Choudhury et al., 2006). These neural mechanisms are implicated in EF and ToM processing, suggesting that both abilities as well as the interrelation between them may continue to develop in middle childhood and adolescence (Blakemore, 2008; Paus et al., 1999). There is very little research on the interrelation between ToM development and EF in these developmental periods (Dumontheil et al., 2010). Three studies investigating the relationships between EF subcomponents and ToM in middle childhood (Austin et al., 2014; Bock, Gallaway, & Hund, 2015; Charman et al., 2001) demonstrated strong correlations between the two abilities. Austin et al. (2014) examined the links between ToM and EF (working memory, inhibition, attention shifting) and suggested that the relation between these abilities persists in middle childhood after a year (6-11 years) even when age, IQ or gender are partialled out. It was also reported that their models provided weak evidence for Perner's (1998) account that early ToM predicts later EF, but stronger support of the early EF impacting later ToM development in school age. Moreover, Charman et al. (2001) using a similar age group (6-10 years) reported that the correlation between EF and ToM was strong and significant. However, when IQ and age were partialled out, this correlation fell below significance. More recently, Bock, Gallaway, and Hund (2015) investigated the associations between EF (working memory, inhibition, and cognitive flexibility) and ToM during middle childhood (7 to 12 years old) as well. Results indicated that cognitive flexibility predicted ToM over and above age and vocabulary, highlighting the strong relations between EF and ToM during middle childhood even beyond their early emergence. This evidence suggests that ToM processing remains efficient as related EF skills mature, but given the limited research on this topic the main question of whether there is true development in ToM during middle childhood and adolescence still remains. Moreover, due to lack of longitudinal studies investigating the link between EF and ToM across time, it is not clear whether the developmental patterns that were exhibited in early childhood (i.e. EF influencing ToM development) still persist across the course of children's development.

The present thesis will thus investigate whether the EF-ToM relation is still present in middle childhood and/or adolescence. Both the cross-sectional and longitudinal designs of this study will aid in investigating the nature of the developmental relationship between EF and ToM and whether the developmental gains in EF contribute to gains in ToM abilities. In addition, as all the aforementioned studies have only examined the relationship between cool EF and ToM, it will be of great interest to investigate the developmental associations (if any) between hot EF and ToM abilities in both typical development and ASD.

### 1.5.1. Theory of Mind and Executive Function in ASD

According to Baron-Cohen et al. (1985), children with ASD are not able to employ a ToM and these deficits are found to persist across age and development. Children with ASD successfully respond to ToM tasks such as false belief but fail to pass more intensive tests including understanding mental states from only focusing on the eyes or voice, understanding faux pas or more subtle tasks such as persuasion (Baron-Cohen et al., 1985; Peterson, Wellman, & Slaughter, 2012; Rutherford, Baron-Cohen, & Wheelwright, 2002). Children with ASD are reported to lack quality friendships and are frequently victims of bullying and isolation (van Roekel et al., 2010; Whitehouse et al., 2009) as they often have difficulties in empathising or inferring mental/emotional states (aspects of ToM). According to Baron-Cohen et al. (1985), individuals with ASD are unlikely to demonstrate a fully developed ToM during their life. Baron-Cohen et al. reported a series of studies (1985, 2002), which found that individuals with ASD, even those with high functioning ASD, perform significantly worse on ToM tasks, than typically developing controls with these deficits persisting into adulthood.

The theoretical accounts proposed by Perner (1998) and Russell (1996) described above, yield opposing predictions with regards to the nature of the developmental relationship of ToM and EF. As ASD's phenotype is traditionally associated with disruptions in EF and ToM, Russell (1997) proposed that impairments in both abilities are thought to be causally involved in the development of the disorder. The co-occurrence of impairments in both ToM and EF in several ASD samples is suggestive of a causal link between cognitive abilities. According to Russell's (1997) Executive Dysfunction hypothesis of ASD, early disruptions in the development of EF may contribute to lack of social flexibility which is characteristic of ASD. As already described, Executive Dysfunction is defined as "a disruption in planning and execution of complex behaviour due to limitations in working memory, or perhaps in some cases, to a specific inhibitory deficit" (Pennington et al., 1997, p.146.). Russell (1997) expanded the Executive Dysfunction Hypothesis suggesting that if EF is necessary for the emergence of ToM, children with ASD who demonstrate disruption in EF will also present deficits in ToM. Moreover, it has been widely suggested that individuals with impaired EF would not be in the position to fully develop a successful ToM (Ozonoff & McEvoy, 1994; Pellicano 2007).

The investigation of the EF-ToM developmental association in ASD could provide evidence aiding in better evaluating the various competing theoretical views about the nature of this relation. Similar to typical development, there is surprisingly limited attention devoted to the examination of the nature of the EF-ToM relationship in ASD. Regarding the preschool period, Pellicano (2007) indicated that ToM and EF (i.e. planning, cognitive flexibility, and inhibition) were significantly cross-sectionally correlated in young children (4-7 years) with ASD even after partialling out the effects of chronological age, verbal, and non-verbal ability. None of the children presented a pattern of impaired EF with intact ToM, suggesting that robust EF abilities may be necessary to provide a platform for the development of ToM in ASD. Kimhi et al. (2014) investigated the relationship between ToM and two aspects of EF (cognitive flexibility and planning) in young children (5 years old) with ASD as well, showing that EF was a significant contributor to the explained variance of ToM tasks. The only relevant longitudinal study of two time points (with a 3 year interval) in early childhood (Pellicano, 2010) indicated that the EF abilities (planning, cognitive flexibility, and inhibition) of children (4-7 years) were a significant predictor of the changes in children's ToM skills three years later (over and above the variance of age, verbal, and non-verbal ability). Taken together, these cross-sectional and longitudinal studies indicate there is a strong association between EF and ToM developmental trajectories across time and development in ASD, and that EF is an important precursor of ToM, especially in young children with ASD (support of Russell's account).

Beyond the 5th year only a few studies have examined the relationship between ToM and EF in middle childhood and adolescence in ASD. Joseph and Tager-Flusberg (2004) demonstrated that performance on ToM tasks was significantly correlated to EF aspects such as inhibition, planning, and working memory in children (5-14 years) with ASD. Furthermore, Ozonoff et al. (1991) also reported significant correlations between selective EF aspects (planning, cognitive flexibility, and working memory) and ToM abilities in children (8-20 years) with ASD, while Zelazo et al. (2002) found that scores on a card-sorting task (used to tap EF cognitive flexibility) were significantly correlated to ToM false belief abilities in children with mild autism. Zelazo et al.'s study was replicated by Colvert, Custance, and Swettenham (2001, as cited in Colvert, Custance & Swettenham, 2002) that also found a strong correlation between ToM false-belief and cognitive flexibility in ASD, even once general and developmental differences were controlled. Ozonoff and McEvoy's (1994) study was the first of the only two longitudinal studies to date having assessed the EF and ToM developmental association in school age and adolescence in ASD. These authors examined the development of EF and ToM abilities over a 3-year interval in adolescents and found that both abilities were significantly impaired and improved little with development in ASD. Specifically both developmental trajectories were found to run in parallel, leading the researchers to imply that EF and ToM are independent constructs but are strongly related at the cognitive level. The second longitudinal study by Tager-Flusberg and Joseph (2005) provided converging support to Russell's theoretical EF-ToM model. School-aged children and adolescents with ASD (5-14 years) were tested on a range of ToM and EF tasks at the first time point and then got their ToM skills re-examined one year later. Children's early EF scores were a significant predictor of the ToM later performance, independent of language and early ToM scores. This preliminary evidence suggests that like typical development, EF control is necessary for the development of ToM in ASD as well. These results however should be treated with caution as Tager-Flusberg and Joseph (2005) did not assess children's EF performance at the second time point; thus it is unclear whether a developmental link would be present in the reverse direction (early ToM predicting later EF).

Findings from the studies presented above make it clear that the EF-ToM association in ASD is undeniable. However due to the lack of longitudinal investigations and methodological limitations of cross-sectional studies, it is difficult to be certain about the precise relationship between EF and ToM. For example, some of the afore-mentioned studies (Joseph & Tager-Flusberg, 2004; Zelazo et al., 2002) did not employ a control group which did not allow for children's performance on EF and ToM to be compared with typically developing peers. Secondly, the establishment of the ToM association with a variety of EF skills refers only to cool EF subcomponents; the role hot EF may play in ToM development has not been examined yet. The research presented in this thesis will investigate the relationship between the developmental trajectory of ToM and EF in ASD both cross-sectionally and longitudinally. Only a few studies have examined this interrelation during middle childhood and adolescence and this study will shed more light on the plasticity of EF and ToM across age. Furthermore, since there is no other study to date that has examined this relation under the lens of the cool and hot EF distinction it would be of great interest to define the extent of the correlation between cool and hot EF and ToM within the spectrum. The cross-sectional examination of the EF-ToM relation will be examined across the whole age span of the present study (7-16 years) but the longitudinal investigation of the interrelation between the two abilities will specifically focus only on middle childhood for the following reasons:

a) Following early childhood which is without doubt a time of tremendous cognitive and socio-emotional development, middle childhood is a developmental stage in which children develop most foundational skills to prepare them for adolescence and adulthood (McAlister & Peterson, 2013). Thus identifying a potential link between EF-ToM across middle childhood could aid in illuminating whether EF contributes to the long-term effects on ToM skills of children with ASD.

b) For methodological reasons, longitudinal investigations should include narrow age cohorts in order to reveal subtle developmental changes; thus it was impractical to follow up the whole age range (7-16) of the sample after one year.

The present research may reveal crucial information about the plasticity of the underlying neural structures of both EF and ToM in school-aged children with ASD.

### 1.6. Executive Function and Adaptive Skills in ASD

In general, adaptive behaviour is part of everyday functioning and refers to “the performance of daily activities required for personal and social sufficiency’’ (Sparrow, Balla, & Cicchetti, 1984, p. 6). Adaptive skills include everyday skills such as effective communication and mutual social relationships that are independently initiated (Klin et al., 2007). Therefore adaptive skills will be used as outcome variables in the current thesis. There is a growing body of research indicating that individuals with ASD present impairments in their adaptive skills, as measured by the Vineland rating scales (Paul et al., 2004; Tomanik et al., 2007). The ASD phenotype is mostly characterised by substantial delays in socialisation, less significant delays in adaptive communication, and relatively intact daily living skills (Bolte & Poustka 2002; Carter et al. 1998).

As described in the introduction, the syndrome of ASD was first introduced by Kanner (1943) and mainly emphasised the social and adaptive behaviour deficits that characterise the disorder. In his review of social behaviour within the spectrum, Lord et al. (1993) included detailed descriptions of the deficits of children with ASD in adaptive behaviours, especially social relationships and communicative interactions. Children with ASD present atypical and impaired social approaches, deficits in social play and imitation skills, as well as limited or no prosocial behaviour. Social deficits in children with ASD have an impact on their social behaviour resulting in significant individual differences in developmental patterns (Volkmar, Carter, Sparrow, & Cicchetti, 1993). Social deficits include joint attention impairments, inability to mutually relate to peers or infer empathy/affection and pretend play deficits (Akshoomoff & Stahmer, 2006). Children with ASD may often prefer to play alone rather than interact with their classmates or friends-even when the other children are of the same age and nearby (Owen-DeSchryver, Carr, Cale, & Blakeley-Smith, 2008). Regarding communication deficits, children with ASD demonstrate speech and language problems from early childhood (Kjelgaard & Tager-Flusberg, 2001). Research has consistently reported significant communication deficits in aspects such as semantics and abstract language processing in children with ASD (Happé 1994; Landa & Goldberg, 2005). Happé (1994) found that individuals with ASD showed difficulties in literally interpreting conversational messages while adolescents with ASD demonstrated deficits in selecting appropriate endings in social conversational contexts (Ozonoff & Miller, 1996).

This adaptive skills profile may be impacted by deficits in cognitive ability (e.g. EF) (Kanne et al., 2011). Indeed, several studies have shown that executive dysfunction is linked with various manifestations of everyday functioning in ASD. Specifically, executive dysfunction may contribute to social deficits (McEvoy et al., 1993), language impairments (Joseph, McGrath, & Tager-Flusberg, 2005) and repetitive behaviours (Lopez et al., 2005); all distinct behavioural features of ASD. Links between EF and social communication one year later were also found in young children with ASD (Griffith et al., 1999) while individual differences in EF predicted social competence 3 years later, (Berger et al., 2003) and "real-life" adaptive skills between 11 and 27 years later (Szatmari et al., 1989) in ASD. Taken together, there is significant evidence that individual differences in EF could account for the adaptive behavioural development in children with ASD.

The limited number of studies which have examined the relationship between EF and adaptive skills (as measured by the Vineland scale) in ASD have yielded significant correlations. Gilotty et al. (2002) investigated the relationship between EF and adaptive behaviour in children with ASD during middle childhood. Their results showed that deficits in specific EF aspects accounted for the impairments in adaptive functioning in children with ASD. In particular, the authors found an inverse correlation between deficits in working memory as well as initiation EF skills and adaptive functioning. However, Panerai et al. (2014) demonstrated contradictory findings to Gilotty et al. (2002) as no correlations were found between EF, socialisation and communication within the ASD group in their study. Nevertheless, Panerai et al. (2014) found that executive dysfunction is significantly associated with impaired socialisation in typically developing children. Pugliese et al. (2015) investigated the role of EF in adaptive behaviour skill deficits in children and adolescents with ASD demonstrating a negative relationship between deficits in EF and adaptive behaviour, especially in young children with ASD. Their correlational and variance analyses indicated that deficits in EF contributed to adaptive impairments in children with ASD.

Finally, although Happé (1994) has raised the importance of adaptive social skills in the development of children with ASD, there is still a big need to collect further evidence about the manifestation of social adaptive skills in ASD within everyday settings such as the classroom or home, in contrast to data generally collected in a laboratory context. Thus, the present thesis will include ecologically valid teacher-report measures (Vineland and BRIEF scales) to investigate the developmental pattern of adaptive skills along with its association to EF, in children and adolescents with ASD. Given the age-related increases in EF problems in ASD compared to typically developing populations, it is important to account for EF when predicting adaptive abilities across development.

## 1.7. Chapter Summary

ASD is a multifaceted neurodevelopmental disorder characterised mainly by social and communicative deficits, unusually repetitive behaviours and impaired social interactions (American Psychiatric Association, 2013). With the primary cause of ASD still unknown, several accounts have been proposed to account for the ASD symptomatology. The neuropsychological approach includes cognitive theories such as the ToM and EF frameworks that have substantially contributed to explain the autism enigma. The present thesis focuses on the Executive Dysfunction account of ASD, fractionating the EF structure into hot and cool EF subcomponents and investigating their developmental patterns across childhood and adolescence. A major point of interest is the investigation of the development of both hot and cool EF across childhood and adolescence in ASD. The importance of studying the development of EF in ASD lies in the heterogeneity of the developmental outcomes of children with ASD that are highly variable, even for individuals at the more intellectually able end of the autism spectrum. Explaining this variability is of critical importance: to discover why developments take place in some areas and not in others, and especially in some individuals and not in others.

EF is defined as the group of neurocognitive skills such as working memory, inhibitory control, and planning, required in goal-directed behaviour and problem solving (Best et al., 2009). EF is suggested as being regulated by neural networks involving the prefrontal cortex with its development spanning from early childhood up to early adulthood. However major advances in EF development occur during the preschool period (Carlson, Zelazo, & Faja, 2013). Several researchers have proposed differentiated models of EF structure but the present study will apply Zelazo and Müller's (2002) cognitive model of hot and cool EF aspects. Cool EF includes the top down cognitive processes that operate in more affectively neutral situations, whereas hot EF refers to top down processes occurring in emotionally significant contexts. The distinction proposed in this model has been supported by neuropsychological research evidence of patients with prefrontal cortex impairment (Carlson, Zelazo, & Faja, 2013). Cool EF is more associated with the dorsolateral prefrontal cortex regions, while hot EF relies on the orbitofrontal cortex. However, the underlying neural structures of both hot and cool EF are suggested to work in combination as part of a unified prefrontal system (Zelazo & Müller, 2002). The distinction between hot-affective and cool-cognitive EF proposed by Zelazo and Müller (2002) could shed more light on the developmental pathways followed in ASD. It has been suggested that ASD might show primary deficits in hot EF and secondary impairments in cool EF (Dawson, Meltzoff, Osterling, & Rinaldi, 1998). The evaluation of EF in children and adolescents could also be crucially informed by behaviour rating scales by raters such as teachers. The present study thus combines both performance–based measures and observational rating scales of "real-life" EF in order to closely investigate the impact of EF as a multifaceted cognitive domain on children's social cognition and adaptive skills.

As discussed, research has shown that EF plays an important role in the developmental outcomes of children with ASD, namely their ToM and adaptive skills (Pellicano, 2007). Although it is not exactly clear whether disruptions in EF influence the emergence of core autistic features directly, it is likely to place children with ASD at risk for impaired developmental outcomes. Thus, the investigation of the individual differences in EF and the developmental pattern it follows could aid clarify whether EF is as a potential source of the heterogeneity in outcomes in autism. The development of the prefrontal cortex, which is suggested to control EF, presents a protracted developmental trajectory. Development commences very early in life and receives a boost during middle childhood. It then continues to develop well into adolescence until it reaches maturation (Diamond, 2002). Traditionally, the development of EF has been investigated mainly using tasks tapping only the cool aspects of EF that lack significant affective or emotional components. Thus, little is known about the developmental trajectory of hot EF during childhood in ASD.

Regarding cool EF, such as inhibition, working memory and planning, development starts during infancy with rapid improvements occurring in early childhood (Garon et al., 2008; Gathercole et al., 2004). Working memory and inhibition continue to develop through adolescence but in terms of planning, it is not clear yet when it reaches maturation levels (Asato et al., 2006). Several studies involving broad age ranges have demonstrated that planning skills as measured by the Tower of London task continue to develop through adolescence (Albert & Steinberg, 2011; Asato et al., 2006; Huizinga et al., 2006). In terms of hot EF, there has been little work to date examining developmental changes in hot EF, not only in the early years of life but also during middle childhood and adolescence. Generally, it has been suggested that hot EF follows a rapid development during the preschool years in typical development (Zelazo & Müller, 2002) and that age-related improvements are demonstrated during middle childhood and adolescence (Prencipe et al., 2011).

Researchers have devoted little attention to the investigation of age-related changes in hot and cool EF in ASD. Research studies examining EF in ASD at several age points have presented mixed results. Although the studies conducted on samples of adolescents or adults have revealed EF deficits in participants with ASD, evidence from research using younger ages such as preschool children has indicated that EF in ASD during the early years of life may be similar to the EF profile of typically developing peers. The investigation of the developmental pathway of EF in older children and adolescents with ASD has demonstrated mixed results. A few studies have shown age-related improvements in EF of participants with ASD (Happé et al., 2006a; Pellicano, 2010) contradicting others that have reported a lack of age-related improvements (Griffith, et al., 1999; Ozonoff & McEvoy, 1994). Taken together, it is apparent that there is not a clear picture of the developmental framework of EF across broad age ranges (from early childhood to adolescence) in ASD due to mixed results.

Middle childhood and adolescence are crucial periods where the development and maturation of EF is occurring. The investigation of the developmental pathway of EF across childhood and adolescence may provide valuable insights into the difficulties children with ASD face in everyday life, as EF is associated with success in social and academic life (Best et al., 2011). Hence, an important focus for developmental research should be focused on investigating the detailed developmental pattern of EF, as well as the links emerging with other important developmental hallmarks, in order to inform prevention and intervention methods.

In the present thesis, two promising areas of cognitive developmental research, EF and ToM, are extensively investigated. The developmental trajectories of EF and ToM have both been found to be strongly associated across childhood in typical development and ASD (Devine & Hughes, 2014; Hughes & Ensor, 2007; Pellicano, 2007). Furthermore, the distinction between cool-cognitive and hot-affective EF has led to the proposal that ToM may be more strongly related to hot EF than cool EF (Zelazo et al., 2005). However, this has yet to be empirically investigated. Studies that consider the role of both hot and cool EF in association to ToM in childhood within ASD would therefore be valuable in gaining a greater understanding, not just of how these cognitive abilities relate to one another, but their joint role in the distinct developmental pathway followed in ASD. The studies presented in this chapter earlier investigated the cross-sectional and longitudinal relationship between cool EF and ToM in ASD and all revealed a strong association between the two domains across early and middle childhood (Joseph & Tager Flusberg, 2004; Kimhi et al., 2014; Ozonoff et al., 1991; Zelazo et al., 2002) and that EF is an important precursor of ToM in children with ASD (Pellicano, 2010).

Adaptive behaviour is an umbrella term including skills that enable individuals to be self-sufficient and socially competent (Sparrow et al., 2005). Adaptive behaviour difficulties can vary in severity in children across the spectrum and symptoms may also change during children's maturation (Akshoomoff & Stahmer, 2006). EF has been found to play a significant role in the development of adaptive skills both in typical development and ASD (Gilotty et al., 2002). EF skills are suggested to influence social communication outcomes such as conversational skills in social contexts and assist in shifting conversational topics according to social-contextual demands or come up with appropriate responses (Landa & Goldberg, 2005). More evidence regarding the emergence and development of social adaptive skills in ASD in real-world settings such as the classroom should be collected. Finally, considering the important effect EF has on adaptive skills, it would be important to account for EF when predicting the development of adaptive abilities in ASD.

In conclusion, there is converging evidence of the important contribution of EF in typical development, combined with significant findings from studies with children and adolescents with ASD. These results suggest that individual differences in the development of hot and cool EF might critically influence the developmental (at the social and behavioural level) trajectories of children with ASD.

### 1.8. Purpose of the Present Thesis and Research Questions

The present study aims to shed more light on the development of EF within ASD and to examine the Executive Dysfunction Hypothesis in association with the cognitive and behavioural outcomes of children and adolescents with ASD. Specifically, it will focus on a conceptual model of EF as proposed by Zelazo and Müller (2002), in which a distinction is made between hot (affective) and cool (purely cognitive) components. In addition, a longitudinal component is included whereby the association between the development of hot/cool EF and ToM across middle childhood in ASD will be explored. An examination of the hot and cool distinction of EF is warranted in order to further investigate the profile of intact and impaired EF abilities in ASD.

There is a growing body of literature in EF research investigating the development of EF across the lifespan; however this research presents several limitations that account for the emerging difficulties in the construction of a truly developmental account of EF. Specifically, the vast majority of research has focused on limited age ranges (e.g. 2-5 years) (Isquith et al., 2004) and especially on pre-schoolers (Garon et al., 2008). This is partially explained due to improvements in performance on EF tasks occurring more rapidly across early childhood

(Carlson & Moses, 2001). Nevertheless, the knowledge about the development of EF processes after the age of 5 years and especially when individuals move from one developmental level to another (childhood to adolescence) is relatively scarce. The purpose of the present study is to set the basis for the construction of such a developmental account, first in typical development, followed by empirical research about the developmental pathway of EF followed in ASD. The present study will examine the developmental pattern of the EF trajectories within ASD addressing tasks tapping both cool and hot EF skills, in order to fully grasp the EF deficits of individuals with ASD. Furthermore, this research will involve the cross-sectional and longitudinal investigation of the association between (performance-based) hot and cool EF and ToM in typical development and ASD. A sample of children with and without ASD will be assessed at two time points, on the same measures of hot and cool EF and ToM in order to explore the cognitive developmental changes and the longitudinal association among these abilities across middle childhood. This research will also involve the expansion of this investigation from middle childhood to adolescence as well. Cross-sectional developmental trajectories of performance-based hot and cool EF, and "real-life" EF ratings, in association to ToM and adaptive skills in both children and adolescents (typically developing and with ASD) will be examined. Moreover, as research on the similarities or differences between the developmental patterns of performance-based measures (hot & cool) and rating scales of EF is minimal, and given that the two different types of EF measures may tap different cognitive constructs, the present thesis aims to address comparisons of their developmental trajectories. Only a few studies have examined the EF-ToM interrelation beyond early childhood and thus this study will provide more clarity on the plasticity of EF and ToM across development. Furthermore, since there is no other study to date that has examined this relation under the lens of the cool and hot EF distinction it would be of great interest to define the extent of the correlation between cool and hot EF and ToM within ASD. Also the longitudinal investigation of the interrelation between the two abilities can aid in illuminating whether there is a true developmental link between EF and ToM, with EF contributing to long-term effects on the ToM skills of children with ASD. In this way, the present study may reveal crucial information about the plasticity of the underlying neural structures of both EF and ToM. Research examining hot EF in ASD has been carried out only with limited samples of adults or older adolescents to date and little is known about these processes in school-aged children. Finally, the present thesis will attempt to examine the relationship between the cross-sectional developmental trajectories of EF and adaptive skills in children and adolescents with ASD as the studies conducted in this field are limited. As the handful of studies having investigated the predictive association of adaptive skills to EF addressed only “real-life” rating EF scales (BRIEF subscales), the present study will investigate whether performance-based EF skills explain any adaptive skills variance as well and which one of the two types of EF measures is the strongest predictor of adaptive skills in ASD and typical development. Finally, no study to date has attempted to investigate the relationship between hot and cool EF aspects and adaptive skills in ASD. Thus, this research may have implications for intervention work aimed at increasing the functional independence of individuals with ASD.

The purpose of this study is to overcome the limitations of the current executive dysfunction models in ASD, aiming to identify a neuropsychological model derived from in-detail, fractionated cognitive-based profiles of development. This could contribute to a more accurate understanding of ASD as a life-long and complicated disorder that may subsequently enable specialists plan more effective interventions.

This thesis will address the following research questions:

1) What is the association between hot and cool EF and ToM in ASD and typical development in middle childhood? Are the early hot and cool EF domains predictors of later ToM (after a 1 year interval) or vice versa in ASD? Is there a link between both hot and cool EF and ToM in ASD across middle childhood (7-12 years)? (Studies One and Two)

2) What are the cross-sectional developmental trajectories of performance-based cool and hot EF and ToM on a larger age group of not only children but adolescents with ASD as well, compared to typically developing peers? Is there any association between the trajectories of hot and cool EF and ToM, expanding such investigation beyond middle childhood (7-16 years) in both groups? (Study Three)

3) What are the developmental trends of performance-based cool and hot EF in ASD compared to typically developing peers in middle childhood and adolescence? Is there a developmental delay or deviance in ASD trajectories relative to controls? (Studies Two and Three)

4) What are the similarities and/ or differences between performance-based EF measures and rating scales of “real-life” EF from school teachers of children and adolescents with ASD compared to typically developing peers (7-16 years)? Which of the two EF assessment methods is the strongest contributor of adaptive skills in ASD and typical development? (Study Four)

# Chapter II

# Methodology

## 2.1. Design

The present thesis adopted both a cross-sectional and a longitudinal approach. The present study first assessed children and adolescents with ASD and typically developing controls ranging between 7 and 16 years of age. A sub-sample of these children (7-12 years) were then followed over one year period. Data were collected at 2 time points; initial recruitment (phase 1) and approximately one year after recruitment (phase 2). At the first time point data were collected from all participants (all children and adolescents) whereas at the second phase, data were collected only from children between 7-12 years (children in primary education settings). Data will provide extended developmental patterns of children with ASD from 7 to 16 years of age. It was ensured that children who participated were selected from schools similar in the socioeconomic background of students. In the present study 3 dependent variables were addressed: ToM mental state/ emotion recognition, ToM false-belief, and adaptive skills. There were three sets of predictor variables: cool EF (inhibition, planning, and working memory), hot EF (delay of gratification and affective decision making) and "real-life" EF. There were two control variables: age and full-scale intelligence. These two recruitment phases formed the basis of the four studies described below.

The first study used a comparative research design in order to examine school-aged (7-12 years) children's with and without ASD performance in cool and hot EF in relation to ToM. It used a cross-sectional design which involved assessing participants' performance only at a given point in time (Olsen & St George, 2004). In the field of developmental psychology it is mostly used to investigate a cross-section of development by addressing a variable of interest in children across different ages. A cross-sectional design is frequently applied in studies with clinical populations comparing different groups at a single point in time (Olsen & St George, 2004). The benefit of a cross-sectional design is that it allows the comparison of several variables simultaneously. Typically, a cross-sectional design examines performance across chronological age, but it could be used across any other continuous variable such as intelligence or time (Knowland et al., 2015).

The second study, referring to the developmental link between hot and cool EF and ToM mechanisms in ASD and typical development, used a longitudinal design approach. Similar to a cross-sectional study, a longitudinal design is also observational; however researchers conduct several observations of the same participants over a specific time period that can range from minutes to years (Fitzmaurice, Laird & Ware, 2012). A longitudinal design enables researchers to track developmental pathways and potential changes in the characteristics of the population tested at both the group and individual level. These studies may establish sequential events as they extend assessment beyond a single time point (Fitzmaurice, Laird & Ware, 2012). A longitudinal design was employed to follow the first cross-sectional study and aimed to establish whether there were developmental links between cool and hot EF and ToM, investigating causality and effect across time in middle childhood.

The third study examined the developmental trends of hot and cool EF in children and adolescents with and without ASD and used the cross-sectional developmental trajectory approach by Thomas et al. (2009). This approach is suggested to be more beneficial when studying developmental disorders in contrast to the traditional matched comparison sample method. Studies investigating language and cognitive impairments in individuals with ASD as well as Williams or Down syndrome have been further enriched in distinguishing different types of developmental delays applying the developmental trajectory approach (Thomas et al., 2009). The unbalanced performance profiles (peaks and troughs of abilities) of children with ASD make it difficult to match participants according to their performance on measures of interest. Despite the matching, inevitable discrepancies such as "covarying" language may account for inconsistent results between the control and ASD group. Besides this, the wide range of intellectual functioning in children with ASD makes the matching procedure on mental and chronological age even more challenging. However, the developmental trajectory approach analyses performance profiles revealing whether the profiles demonstrated in ASD overlap or deviate from profiles as presented in typical development. More specifically, it involves constructing functions of task performance and age (either chronological or mental) (Thomas et al., 2009). The chronological age of participants is used as a basis to compare the cross-sectional developmental changes in the trajectories of tasks such as EF across typically and atypically developing groups. Trajectories that link performance in measures of mental age with performance in cognitive tasks aid in revealing the developmental relations that exist within disorders which show uneven cognitive profiles (Thomas et al., 2009). The compared trajectories of interest can be used to identify delayed onset on given tasks and the slower rates of development of EF abilities in the ASD group. This type of methodological design could reveal if the developmental trends in ASD follow a linear progression or not (Thomas et al., 2009). Moreover, the trajectories approach allows researchers to define profiles of EF impairments that may yield the potential to distinguish subcategories among children with ASD. Conceptually, the trajectories approach is similar to standard Analyses of Variance (ANOVA). However, in this approach, instead of testing the difference between group means, the difference between the straight lines, used to depict the developmental trajectory in each group, is evaluated (Henry et al., 2013; Thomas et al., 2009; Thurman et al., 2015). More specifically, in order to compare linear regressions, the Analysis of Covariance function within the General Linear Model (ANCOVA) is adapted (chronological age for example is used as a covariate). This methodology is thought to be equivalent to introducing dummy variables in linear regression models, when one is interested in assessing the significance of dichotomous or categorical variables and their interaction with continuous variables (Suits, 1957). This method requires the specification of three appropriate effects within the model: main effect of Group, main effect of the covariate and the interaction between Group and the covariate. When those are computed, the differences between the slope and intercept of the lines depicting the developmental trajectory of each group are evaluated, instead of comparing the cross-sectional group means. In the present study, the main effect of group (ASD or control), main effect of covariate (chronological age, FSIQ) and the interactions between group and covariate were investigated.

The fourth study investigated the cross-sectional developmental trajectories of “real-life” EF abilities (as rated by teachers) of children and adolescents with and without ASD and compared them with those of performance-based EF skills (from Study Three). It also examined which one of the two types is the strongest predictor of adaptive skills. This study was a cross-sectional comparative design that utilised both a performance-based along with an ecological approach (as perceived by each student’s teachers) for the measurement of EF. There is a growing body of research suggesting that combining performance-based with “real-life” EF measures may investigate whether these domains intercorrelate and provide an explanation for the heterogeneous performance of EF in children and adolescents with ASD (Griffith et al., 1999; Ozonoff, Pennington, & Rogers, 1991; Toplak et al., 2008; Toplak, West, & Stanovich, 2013).

### 2.2. Power Analysis

Before recruiting participants, an a priori power analysis was conducted in order to determine the number of participants necessary to achieve adequate power for multivariate analysis. Statistical power is used to calculate the minimum sample size required in order for analysis to reveal an effect of a given size (Ellis, 2010). According to the criteria discussed in Stevens (2002), a power magnitude of $\geq .80$ is considered adequate for multivariate analyses with a medium effect size of .50 (Stevens, 2002). G*Power 3.1.0 (Faul, Erdfelder, Lang, & Buchner, 2007) was used to identify the appropriate sample size of participants necessary to achieve adequate power with medium effect sizes. For multivariate analysis with two groups and 8 response variables, a sample size of 52 participants was needed in order to achieve a medium effect size of .50 with adequate power of .80 at $\alpha = .05$. The size of the sample recruited for the present study was more than 150 participants which provided adequate power for the subsequent statistical analysis.

### 2.3. Participants

One hundred and seventy six (176) children were recruited from several mainstream and special education schools in the South East of England to participate in the study. Eighty five children (85) held an official diagnosis of ASD and the remaining ninety one (91) served as a control group. The eighty five ASD participants were recruited from a variety of special education schools and provision units within mainstream settings where admission required a formal diagnosis of ASD. ASD participants had been diagnosed by qualified clinicians and psychologists using DSM-IV (Diagnostic and Statistical Manual of Mental Disorders; American Psychiatric Association, 1994) or DSM-V (American Psychiatric Association, 2013) criteria. Students with ASD for whom detailed information about their diagnosis was lacking were not included in the study.

Exclusion criteria included the presence of a diagnosed psychiatric illness, comorbid conditions (i.e. Attention Deficit Hyperactivity Disorder (ADHD), and/or Tourette syndrome, seizures or colour blindness) and Full Scale Intelligence Quotient (FSIQ) below 70 (as determined by the abbreviated version of the Wechsler Intelligence scales (two subtests: vocabulary and matrix reasoning; Wechsler, 1999)). These criteria led to the exclusion of six cases in the ASD group, resulting in a final ASD group size of seventy nine (79) children with a clinical diagnosis of ASD. Fifty six (56) typically developing children were recruited from mainstream primary schools (Years 2-Years 6; Ages 6/7 – 10/11 years) and thirty five (35) typically developing adolescents from mainstream secondary schools (Year 7-Year 11; Ages 11/12 – 15/16 years). Based on school records, all typically developing participants had English as a first language, had never been diagnosed with ASD or had family history of ASD, had no other mental health disorders, ADHD, dyslexia or a learning disability. Participants spanned a wide range of socioeconomic status (SES) groups; however the majority were of White British origin and average SES for England. Children were assigned to two different cohorts based on their age: 7-12 years old and 12-16 year old. At initial recruitment children ranged from 7 years 3 months to 16 years 1 month. Table 2.1 shows descriptive characteristics of participants of both groups at the first phase. Both groups were matched for age [$t$ (170) = -1.21, $p$= .23] and FSIQ [$t$ (170) = 1.79, $p$= .8] (see table 2.1 for Means and SDs). At the second phase 37 children with ASD along with 45 typically developing peers from the first cohort (7-12 years) were followed up. The class teachers and teaching assistants of the participating children were also recruited in order to provide information on the children's adaptive skills and "real-life" EF through questionnaires.

**Table 2.1. Descriptive characteristics of participants in both groups at phase 1.**

| | Group | |
|---|---|---|
| | ASD | Control |
| Variable | (*n*=79) | (*n*=91) |
| Age (in years) | | |
| *M (SD)* | 11.27 (2.56) | 10.80 (2.49) |
| Range | 7-16 | 7-16 |
| FSIQ total score | | |
| *M (SD)* | 95.85 (15.09) | 99.78 (13.54) |
| Range | 70-127 | 72-135 |

## 2.4. Measures

For a summary of the tasks employed please see table 2.2.

### 2.4.1. Executive Function

In the present study, performance on both hot and cool EF subcomponents was assessed.

### Cool Executive Function

The cool EF aspects that were examined included inhibition, working memory, and planning. Inhibition and working memory were chosen first because ongoing research shows that they are core EF skills, functionally distinguished as separate skills across childhood (Anderson & Reidy, 2012; Hummer, Wang, Kronenberger, Dunn, & Mathews, 2015; Schoemaker, Bunte, Espy, Dekoviæ, & Matthys, 2014). The more complex cool EF planning was also employed as it is suggested to build on these core, higher-order EF (Collins & Koechlin 2012, Lunt et al. 2012). Planning has been found to correlate with inhibition and working memory in children (Senn et al., 2004). Second, it has been found that children with ASD present deficits in these cognitive skills (Hill, 2004; Pellicano, 2007; Joseph et al., 2005). There is an increasing body of evidence implicating these aspects in children's developmental and behavioural outcomes in ASD (Pellicano, 2007, 2010; Ozonoff et al., 1991; Joseph & Tager-Flusberg, 2004).

#### 2.4.1.1. Inhibition

***Go/No-Go paradigm (Mueller & Piper, 2014)***

The 'R' and 'P' version of the Go/No-Go paradigm developed by Mueller and Piper (2014) was used in the present study to measure children's cognitive inhibition. This was a computerised task that was retrieved from a psychological free cross-platform system for designing and running computer-based experiments and tests (PEBL). The task was presented to participants using a laptop with a 13.5" screen. Children responded by pressing the right shift key of the keyboard. An image of either the letter P or letter R appeared in the centre of the screen on a black background. Children were then instructed to press the button only when the letter P was shown (Go trials) and to avoid pressing it for the letter R (No-Go trials). On the second block of trials, the pattern was reversed and children were asked to press the button when the letter R appeared (Go trials) and to avoid pressing it when P was presented (No-Go trials) this time. The image of the P or R was presented for 1500msec, with an inter-stimulus interval of 1000msec. There was no feedback provided after a correct or incorrect response.

At the beginning of the task instructions were displayed on the screen that the children would either read by themselves or were read by the researcher. Children first completed some practice trials before completing the actual test trials that were divided into two blocks. The whole procedure lasted approximately 10 minutes. In order to assess children's cognitive inhibition, the proportion of incorrect No-Go trials along with average response time to both condition trials were recorded. Lower scores indicated better performance. This Go/No-Go paradigm was carefully chosen as it is developmentally appropriate for the age range of children and adolescents being assessed in this study. Test-retest reliability has been found to be good for the Go/No-Go paradigm of PEBL platform (.80) (Mueller & Piper, 2014). Children completed this task at both assessment phases.

#### 2.4.1.2. Planning

***Tower of London (Shallice, 1982)***

In order to assess children's planning skills, the Tower of London (ToL) task (Shallice, 1982) was used. The ToL has been widely used to assess planning ability across the lifespan, from children as young as 3 years of age to adulthood (Best et al., 2009; Monks, Smith, & Swettenham, 2005). This task involves two identical wooden pegboards that are placed next to one another in front of the child. Each pegboard has three wooden pegs on which three wooden beads can be placed (one green, one red, one blue). The child is required to replicate a series of patterns constructed by the researcher in a set number of moves. The researcher first explained the task to the child and then presented the child with three 3-move problems as a practice. If required the researcher helped the child solve the practice problems to ensure that the child understood the task. Children were then presented with the 12 trials from Shallice's (1982) original problem set: two 2-move tasks; two 3-move tasks; four 4-move tasks; and four 5-move tasks. Figure 2.1 illustrates part of the procedure.

The child's pegboard was always placed directly in front of the child and the researcher's pegboard was always placed on the right side of it. The task was carried out in line with the approach used in Monks et al. (2005) and Poland, Monks and Tsermentseli (2015). More specifically at the start of each problem trial the researcher first arranged the child's beads into the start position and then constructed the test problem on their own pegboard (see Figure 2.1). In order to successfully complete each problem the child needed to adhere to two rules. First, the child needed to complete the trial in the specified number of moves. The researcher informed the child of the required number of moves at the start of each trial. Second, only one bead was to be removed from a peg at a time. Each problem could be presented to the child a maximum of two times. Children were given two minutes to complete each problem. If two minutes passed and the child had not completed the trial then the trial was marked as a fail and the researcher moved the child onto the next problem. The task was stopped after the child completed all problems or failed two problems consecutively. In the present study, children were presented each problem just once rather than three times as was done in Monks et al.'s (2005) study because the children in the current research were much older and also because it was thought that multiple presentations of a test problem might reduce the novelty of the task as already suggested (Culbertson & Zillmer, 1998).

In terms of the scoring, children's performance was assessed based on the method described in Monks et al. (2005) and Poland et al. (2015). Specifically, the number of problem trials each child successfully completed was measured. Children were awarded 1 point if they completed the problem successfully at once and 0 points if they failed to complete the problem. Thus, scores ranged from 0 (none correct) to 12 (all correct on the first trial). The number of errors children made on each trial was also recorded. An error referred to making more moves than was specified or moving more than one bead from a peg simultaneously. The total number of errors on all attempted test trials was summed. Finally solution time for each trial was measured. Solution time was the time from presentation of the problem to the completion of the problem (unless it was discontinued). The average solution time for the total number of the attempted test trials was calculated at the end. ToL task was carefully chosen as it is developmentally appropriate for the age range of children and adolescents being assessed in this study. Children completed this task at both assessment phases.

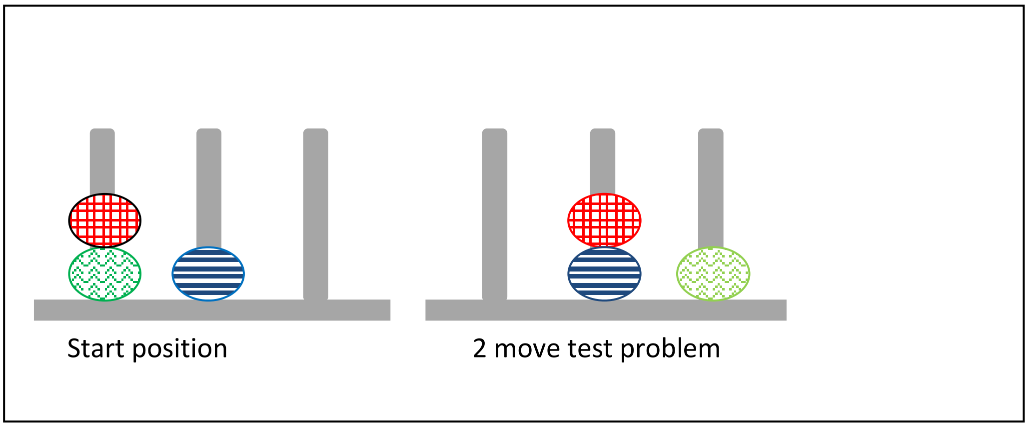


Figure 2.1. Diagram illustrating the Tower of London start position and an example of two move test problem presented as practice before the actual assessment.

#### 2.4.1.3. Working Memory

***Working Memory Digit recall and Backwards Digit recall (WISC-III; Wechsler, 1991)***

In order to assess children's working memory, the digit span forward and backwards subtests from the Wechsler Intelligence Scale for Children-3rd edition were used. The aim of this test relies on children managing to recall each sequence in the exact same order as it was presented by the examiner (e.g., "Listen carefully and then say the list back to me in the exact same order: 12469"). Both tasks were carried out in compliance with the guidelines presented in WISC-III (Wechsler, 1991). The researcher read aloud a series of number sequences to the child at a rate of one number per second. When a participant responded correctly to 4 trials within a block, the examiner proceeded to the next one. In the backwards digit recall task, the series of numbers should be repeated in reverse order. Children were required to recall the list starting with the last item heard and end with the first item presented (e.g., '4598' would become '8954'). When a participant responded correctly to 4 trials within a block, the examiner proceeded to the next one. Each block included 2 trials at each span length. The tasks commenced with digit sequences of 2 and increased progressively to 9 digits on the forward and 8 digits on the backward subtest.

In terms of scoring, children were awarded 1 point for each correct trial while the task ceased when the child failed both trials at any given span length. The sum of the points awarded for both the forward and backward subtest created a composite working memory score. Raw scores were then converted into standardised scores. WISC-III was developed to be used with children aged between 6 to 16 years; thus the age range used in the present study did not deviate from the standard norm. Furthermore, the test-retest reliability for the forward subtest has been found to be very good (.81) and good for the backward test (.62) as suggested by Alloway (2007). Children completed this task at both assessment phases.

### 2.4.2. Hot EF

The hot EF subcomponents that were introduced in the present study included affective decision making and delay discounting ability. Hot EF aspects have not been as extensively studied as the cool EF aspects, especially in ASD. Affective decision making and delay of discounting ability were thus chosen to be investigated as emerging evidence has demonstrated that children with ASD present impairments in both domains which may be implicated in disruptive behaviour (Brock et al., 2009; Garner & Wajid, 2012; Kim et al., 2014). The present study attempted thus to explore the development of hot EF across the spectrum as well as the relationship to social and behavioural outcomes in ASD.

#### 2.4.2.1. Affective Decision Making

***IOWA Gambling task (Bechara et al., 1994)***

A modified version of the IOWA gambling task developed by Bechara et al. (1994) was used in the present study to assess children's affective decision making at both phases. The IOWA gambling task has been found to be developmentally appropriate for middle childhood and adolescence (Hooper et al., 2004; McNally et al., 2012; Smith et al., 2012). IOWA gambling task was presented to the children using a laptop with a 13.5" screen. In this computerised version the participants were presented with four decks of cards labelled A, B, C, and D on the screen. They were then told they could use the mouse to select a card from any of the four decks they wanted each time. The participants were expected to make approximately 100 card selections throughout the whole procedure, without knowing in advance how many trials they may have. Two of the decks (A and B) were equivalent in terms of overall net loss, and two of the decks (C and D) were equivalent in terms of overall net winning. The wins and losses for each card selection were set so that in every block of 20 cards from Deck A or Deck B there would be a total potential gain of £1,000, interrupted by unpredictable losses amounting to £1,250. For Decks C and D, the gains for each block were total £500, interrupted by potential net losses of £250. In Deck B the loss was less frequent, but of a higher magnitude than in Deck A, where the loss was more frequent but in smaller amounts. Similarly, in Deck D losses were less frequent and of higher magnitude relative to those in Deck C. Thus, Decks A and B were equally "disadvantageous" in the long term, whereas Decks C and D were equally "advantageous." The task identified whether children could actually learn from experiences with negative outcomes and make appropriate choices after. Children's affective decision making was examined on the basis of whether they made predominately advantageous or disadvantageous decisions. Based on the approach used by Verdejo-Garcia et al. (2006), net scores for the IGT were calculated by subtracting the number of disadvantageous choices (decks A and B) from the number of advantageous choices (decks C and D) and then divided by the total trials number. The IGT was carefully chosen as it is developmentally appropriate for the age range of children and adolescents being assessed in this study. Children completed this task at both assessment phases.

### 2.4.2.2. Delay discounting ability

***Delay Discounting Task (Richards, Zhang, Mitchell, De Wit, 1999)***

The Delay Discounting task was used in the present study in a computerised version to assess children’s ability to measure the extent to which participants do discount future rewards (Richards et al., 1999). This task originally included the forced-choice between different amount of money after different delays or with different chances. However, as the task was being given to school-aged children it was decided to modify it and completely remove the probability questions. Children were told that they had to choose (hypothetically) between an immediate amount of money or £10 available after a delay. The test consisted of about 70 such questions (i.e. (a) Would you rather have £10 for sure in 30 days or (b)£2 for sure right now?). Using an algorithm, the amount of immediate money was adjusted across trials until an amount was reached that was determined by previous choices as being equivalent to a delayed £10 reward; until the participant was indifferent between the two choices (random adjusting procedure; for more details see Richards et al., 1999)[1]. For every participant, this indifference point (the amount of immediate money judged to be equivalent to £10) signified the subjective

[1] Random adjusting- amount procedure (Richards et al., 1999) : << In this description the delayed £10 will be referred to as the standards. The adjusting amounts of immediate money will be referred to as the variable amounts. The variable amounts correspond to the randomly selected amounts between top and bottom limits. These limits changed according to the subjects’ choices as the session progressed. In order to minimize the effects of subject error (e.g., due to inattention), there were two top limits (the maximum top limit and the minimum top limit) and two bottom limits (the maximum bottom limit and the minimum bottom limit). The maximum top limit was greater than the minimum top limit, and the maximum bottom limit was always less than the minimum bottom limit. These four limits could vary independently. On each trial, the participant made a choice between a standard and a variable amount. On the first trial for each standard, the maximum and minimum top limits were set to £10, and the maximum and minimum bottom limits were set to £0. On all trials, the variable amount was randomly selected from the range of values between the maximum top limit and the maximum bottom limit in £0.50 increments (i.e., on the first trial the variable amount could be anywhere between £0 and £10 in £0.50 steps). The range of values from which the variable amount was chosen was adjusted systematically on succeeding trials. That is, if the participant chose the standard, the top and the bottom limits on the trial following it increased according to three rules: (a) If the variable amount was greater than the minimum bottom limit, the minimum bottom limit was set equal to the variable amount and the maximum bottom limit was set equal to the previous minimum bottom limit. (b) If the variable amount was less than the minimum bottom limit, the maximum bottom limit was set equal to the variable amount and the minimum bottom limit was left unchanged. (c) If the variable amount was greater than the minimum top limit, the minimum top limit was set equal to the current variable amount and the maximum top limit was set equal to £10. This procedure for increasing the top and bottom limits caused the variable amount to increase on the following trial. However, if the participant chose the variable amount, the top and the bottom limits on the next trial decreased according to three rules: (a) if the variable amount was less than the minimum top limit, the minimum top limit was set equal to the variable amount and the maximum top limit was set equal to the previous minimum top limit. (b) If the variable amount was greater than the minimum top limit, the maximum top limit was set equal to the variable amount and the minimum top limit was left unchanged. (c) If the variable amount was less than the minimum bottom limit, the minimum bottom limit was set equal to the variable amount and the maximum bottom limit was set equal to £0. This procedure for decreasing the top and bottom limits caused the variable amount to decrease on the following trial. When the difference between the maximum bottom limit and the maximum top limit reached £0.50, the corresponding variable amount was taken as the estimate of the indifference point. After an indifference point had been determined for a particular standard, questions about that standard were no longer presented. >>

value of the delayed large reward (Richards et al., 1999). Delay discounting was determined by five delays (0, 10, 30, 180, and 365 days later). In terms of scoring, the procedure described in Myerson et al. (2001) was followed, where the indifference points were used to estimate delay discounting. Thus, indifference points were established within participants and were plotted against time (delay). Indifference points and delays were normalised, by expressing indifference points as proportions of the amount of the maximum delayed reward (£10) and the delays as proportions of the maximum delay (365 days). These normalised values were used as the x (delay) and y (indifference points) axes in order to plot the discounting function. Vertical lines were then drawn from each data point on the x axis, creating four separate trapezoids. The formula $(x2-x1) \cdot [(y1 + y2) / 2]$ was used to calculate the area of each trapezoid. The areas under these discounting curves (AUC) were calculated by summing the resulting trapezoids. The AUC method of quantifying discounting behaviour has been frequently used (Dixon et al., 2003; Harrison & McKay, 2012) and provides a straightforward measure of discounting that is not linked to any theoretical framework (Myerson et al., 2001). This task was chosen because it is developmentally appropriate for the age range of children in the present study and has previously been carried out with children and adolescents (Wilson et al., 2011; Dias et al., 2013). Children completed this task at both phases.

### 2.4.3. ToM

Two measures of ToM were used in the present study: ToM understanding of false belief and ToM mental state/ emotion recognition. False belief understanding was examined because it is the most extensively assessed measure of children's ToM (Wellman et al., 2001) and has been found to have strong links to EF in children with ASD (Kimhi et al., 2014; Pellicano, 2007). Mental state/ emotion recognition is a fundamental part of ToM and empathising in general (Golan et al., 2006) and research has indicated that children and adults with ASD present core difficulties in this ToM index (Baron-Cohen, 1995; Hobson, 1994). Mental state/ emotion recognition is not as widely assessed as false belief in ASD while the relationship to hot and cool EF is yet to be explored. Besides, most mental state/ emotion recognition studies have mainly put emphasis on the recognition of six "basic" emotions (happiness, sadness, fear, anger, surprise and disgust), omitting more complex emotions. The present study addressed these concerns.

### 2.4.3.1. False Belief Knowledge

***Sandbox Task (Begeer et al., 2012)***

In order to measure children's false belief understanding, the Sandbox Task was used. This task was originally based on Wimmer and Perner's (1983) classic false belief task. The children looked at various pictures on a sheet of paper. They were told that this task was about a father and a daughter (Sanne) planting flower bulbs in a Sandbox. They should listen carefully while the researcher was telling the story and if they wanted they could read along from the paper. The researcher showed the children the picture of a sandbox and told them the father decided to bury the flower bulb at the location of the cross. When the father went away to bring a watering can Sanne decided to move the flower bulb and bury it in a different location (children were shown the picture in Appendix B). The researcher then asked the children one false belief question: "When Sanne's dad comes back with the watering can where will he give water to the flower bulb? You have to draw a cross". Children were therefore required to attribute a false belief to Sanne's dad.

In terms of scoring, the difference between the original hiding location of the flower bulb (0 cm) and the location where the participant indicated dad had to look for the flower bulb was measured (in centimetres). When participants indicated a location in the direction of the second hiding location of the flower bulb (6.3 cm), this received a positive bias score. When participants indicated a location in the opposite direction of the flower bulb, to the right of the original hiding location, this received a negative bias score. The Sandbox task has been used with a wide range of ages and is developmentally appropriate for the age of participants in the current study (Begeer et al. 2012). Moreover, it has been found to have a good internal consistency and test-retest reliability (.78) (Begeer et al. 2012). Children completed this task at both phases.

### 2.4.3.2. ToM mental state/ emotion recognition

***Reading the mind in the eyes* (*Baron-Cohen et al., 2001).***

In order to assess ToM mental state/ emotion recognition, the Reading the Mind in the Eyes task (children's version) developed by Baron-Cohen et al. (2001) was used. This task was chosen as it is a widely used ToM test that measures the ability to decode the feelings and thoughts of others from the eyes. The test can also be considered an emotion recognition test (Vellante et al., 2013). The Reading the Mind in the Eyes test includes the presentation of several pictures of people's eyes with every picture being accompanied with four words around it. Participants were asked to look carefully at the picture and then choose which word they think best described what the person in the picture was thinking or feeling. Successful performance on all items (28 in total) required children/adolescents to recognise the correct emotion or mental state. The researcher clarified that some questions would seem quite easy and some of them quite hard. Participants were asked to choose one of the terms even if they said that any term was quite right, thus conforming to a forced-choice procedure. One point was given to each correctly reported response. Scores range from 0 to 28. The Reading the Mind in the Eyes has been found to have a good internal consistency and test-retest reliability (.82) (Baron-Cohen et al., 2015). The Reading the Mind in the Eyes task has been used with a wide range of ages so is developmentally appropriate for the age of children in the current study (Olderbak et al., 2015). Children completed this task at both assessment phases.

### 2.4.4. Mental Ability

***Wechsler's Abbreviated Intelligence Scale (WASI; Wechsler, 1999)***

Children's general mental ability was assessed using the abbreviated version of the Wechsler's Intelligence scale (WASI, Wechsler, 1999). This short, reliable scale measured children's general intellectual ability. It was used to assess the verbal ability and nonverbal ability of participants as well. Thus only two (out of four) subtests were employed; the *Vocabulary* and *Matrix Reasoning.* Scores are standardised around a general population mean of 100 (Wechsler, 1999). The IQ of participants was measured in the present study because the cross-sectional developmental trajectories of EF in both groups were examined having both chronological age and IQ as baseline. The WASI was used in the current study as it was developed for use across the lifespan, starting from 6 years of age (Wechsler et al., 1999). The testing was carried out in compliance with guidelines laid out in the manual. Standardised scores by age were used in the present study.

### 2.4.5. Teaching Staff Measures

In the present study, teaching staff ratings of children's adaptive skills (communication, daily living skills, and socialisation) as well as "real-life" EF were obtained. Teachers and teaching assistants (staff supporting qualified teachers by helping develop programmes of learning activities and adapt appropriate materials) are valuable sources of information as they spend a substantial amount of time with children. They are external to peer groups and observe their students' behaviour in a variety of school activities (Cheah, Nelson, & Rubin, 2001). Researchers tend to use teachers' ratings as they are able to provide objective information about children's behaviour (Coie & Dodge, 1988). Questionnaires from teachers and teaching assistants were obtained and combined in an attempt to gain multiple perspectives. It should be noted at this point that early research on multiple informants in child and adolescent psychopathology (see Smith, 2007 for a review) generally suggested that for older children the child is often the best informant, followed by parent and then teacher reports. However, recent studies (Dekker et al., 2017; Miranda et al., 2015) using the BRIEF rating scales supported the reverse pattern. These studies included both parent and teacher-report BRIEF EF ratings in order to examine the relative impact of these different EF ratings on social outcomes and indicated that it is the teacher EF ratings along with performance-based EF that have a complementary role in outcome variables (parent-report EF ratings did not explain any significant variance).

#### 2.4.5.1. "Real-life" Executive Function

***Behaviour Rating Inventory of Executive Function – Teacher Report (BRIEF-TR; Gioia et al., 2000).***

In order to assess the "real-life" EF abilities of children, teaching staff (teachers and teaching assistants) completed the BRIEF-TR for each child in their class participating in the study. Teaching staff completed BRIEF at the first phase. This scale (84-items) is a behavioural rating that includes a teacher questionnaire to obtain information about the EF in natural contexts such as the school or home. The BRIEF was the only available measure of children and adolescents' "everyday" EF abilities. The BRIEF measured two broad areas of EF: *behavioural regulation*, the ability to shift and modulate emotions and behaviour via appropriate inhibitory control; and *metacognition*, the ability to cognitively self-manage tasks and monitor performance. This scale offered the further advantage of sampling multiple EF processes (i.e. inhibition, shifting, emotional control, initiation, working memory, planning, organisation, organisation of materials, and self-monitoring) across a wide age range (5–18 years). The BRIEF also included validity scales measuring Inconsistency and Negativity.

The minimum and maximum ages of children in the present study were 7 and 16 years respectively. Thus the age range used here did not deviate from the standard age range of the scale. Teaching staff rated how true each statement describing children's behaviour over the past 6 months. Teaching staff were asked to circle their responses: N if the behaviour was *Never* a problem, S if the behaviour was *Sometimes* a problem, and O of the behaviour was *Often* a problem. Numbers that correspond to each rating (i.e., 1 for Never, 2 for Sometimes, and 3 for Often) were then summed for each scale obtaining a raw score. Raw scores ranged from 73 to 219 with higher scores suggesting an EF dysfunction. Raw scores were converted into T scores separately for boys and girls. The items that were selected for inclusion in the BRIEF have been determined based on inter-rater reliability correlations as well as item-total correlations that had the highest probability of being informative for clinicians (Isquith et al., 2008). The BRIEF has been indeed found to have good reliability, with high test-retest reliability (*r*s ≈ .88 for teachers, .82 for parents), moderate correlations between parent and teacher ratings (*r*s ≈ .32 – .34) and high internal consistency (Cronbach's alphas ≈ .80 – .98). Evidence regarding the convergent and divergent aspects of the BRIEF's validity derives from its association with other behavioural functioning measures (Isquith et al., 2008). The BRIEF has demonstrated significant utility in research contexts as it has been found to differentiate clinical and non-clinical populations such as for example identifying children with and without ADHD (Jarratt et al., 2010; McCandless & O'Laughlin, 2007; Sullivan & Riccio, 2007).

#### 2.4.5.2. Adaptive Skills

***Vineland Adaptive Behaviour Scales (VABS-T; Sparrow et al., 2005)***.

Teaching staff also completed the Adaptive Behaviour Scale of the VABS-T for each child from their class who participated in the study. The VABS was designed to assess adaptive behavioural skills in socialisation, communication, and daily living of individuals from birth to adulthood (Sparrow et al., 1984). These domains could be expressed as raw scores, standard scores, age equivalent scores, percentiles, or adaptive levels. In addition, the four domains were divided into the following sub domains: (a) communication domain (receptive, expressive, and written language); (b) daily living skills (personal, domestic, and community); (c) socialisation (interpersonal relationships, play and leisure time, and coping skills); and (d) motor skills (gross and fine motor) (Sparrow et al., 2005). Raw scores were summed to create composite scores.

For young children aged from birth to 6 years (and 11 months), the Adaptive Behaviour Composite score included four domains: (a) Communication, (b) Daily Living Skills, (c) Socialisation, and (d) Motor Skills. For children equal to or older than 7 years, the Adaptive Behaviour Composite score comprised of three domains which included: (a) Communication,

(b) Daily Living Skills, and (c) Socialisation (Sparrow et al., 2005). Teachers rated how true each statement was on a 2-point Likert scale, with '0' meaning 'never', '1' meaning 'sometimes or partially', and '2' meaning 'usually'. Age equivalent scores and standard scores can be obtained for each domain, and scores can be combined to create overall Adaptive Behavior Composite (ABC) standard score. The VABS has been found to have a good internal consistency (α in the high .80s to .90s) (Sparrow et al., 2005). The Vineland scales have been widely used to measure adaptive skills in ASD across childhood (Cederlund et al., 2008; Kenworthy et al., 2010; Gilotty et al., 2002; Paul et al., 2004)

**Table 2.2. Summary of tasks used in the present study.**

| Task | Rater | Variable domain |
|---|---|---|
| Go/No-Go | Child | Cool EF: Inhibitory control |
| Tower of London | Child | Cool EF: Planning |
| Digit Span | Child | Cool EF: Working memory |
| Delay Task | Child | Hot EF: Delay of discounting |
| Iowa Gambling Task | Child | Hot EF: Affective decision making |
| Reading the Mind in the Eyes | Child | ToM: mental state/ emotion recognition |
| Change of Location (sandbox task based on Sally-Anne) | Child | ToM: False belief knowledge |
| Wechsler's Abbreviated Scale of Intelligence (WASI) | Child | Full Scale Intelligence Quotient (mental ability) |
| BRIEF-TR | Class Teacher and Teaching Assistants | "Real-life" Executive Function abilities |

| | | |
|---|---|---|
| Vineland Adaptive skills | Class Teacher and Teaching Assistants | Adaptive skills (socialisation, communication, and daily living skills) |

Note: All these measures (excluding BRIEF & Vineland) were carried out in both assessment phases.

## 2.5. Procedure

### 2.5.1. Recruitment

The researcher initially contacted the head teacher of more than ninety five primary and secondary schools, both mainstream and special education, in London, Greater London, Surrey and Kent. Thirty of these schools agreed to participate. Once informed consent was obtained from the head teachers of the participating schools, letters were distributed by the schools to teachers and teaching assistants from Year 2 (6-7 years old) to Year 11 (15-16 years old) asking them to participate in the study. When informed consent was obtained from the class teacher, a letter was given to send home with each child in their class requesting parent/caregiver permission for the child to participate in the study. Positive consent was obtained from parents/caregivers of all the children (100%) in the present study.

The researcher made efforts to increase participation rates in a number of ways The letters sent out to the parents /caregivers were printed on brightly-coloured paper and headed with the title “RESEARCH STUDY/IMPORTANT INFORMATION” in bold font. Along with consent forms and information sheets generated by the researcher, a letter from the head teacher of the school outlining the school’s interest in the research was sent out to families. These letters mentioned how useful the outcomes of this study might be for educational professionals and that the researcher would go back to the school upon completion of the research to give feedback and a summary of the results to school staff. These methods were used because they have been found to increase response rates among parents/caregivers (Glenny et al., 2013; Ellickson & Hawes, 1989). Generally the researcher developed a recruitment strategy with help from the SENCOS (Special Educational Needs Coordinator). More specifically, the teachers first distributed the consent letters to the children in their class to take home and spoke to parents/caregivers about the study when the children were collected from school. In the second stage, if fifteen days later there were no responses back, teachers were asked to remind children to bring back the letter to the school. The researcher worked with a member of staff at each school who was motivated to aid in recruitment.

### 2.5.2 Consent in typical development and vulnerable (ASD) groups

Children and adolescents with ASD were recruited ensuring every precaution about recruitment of vulnerable groups was taken. Every effort was made to include only high functioning (IQ>70) ASD participants as children/adolescents with a lower intelligence score would not have been able to complete the assessment tasks. Furthermore, parents/carers of children with ASD often refuse to give consent for their child to participate in research studies feeling afraid that this may label or harm their child. Thus, through recruitment letters, parents of children with ASD were assured that all information would be anonymous and no personal details would be published. All parents (both with typically developing children and ASD) were explicitly assured that all data would be kept strictly confidential and that there were not any disadvantages and risks associated with this study. It was made clear that the study was not a medical study and all tasks addressed to their children would be fun and age appropriate. Parents/caregivers were also informed that the information from this study would help to further our understanding of the relationship between brain and social development in children and adolescents with ASD. The assessment of young participants with ASD has been often found to be more challenging than the control group. Children, and especially adolescents with ASD, tend to be more inflexible with strangers or socially withdrawn when taken out of their "comfort zone" (Bellini, 2004; White et al., 2009). In order to ensure my presence in schools would not cause any inconvenience, I made sure to visit children's classrooms a few days before the actual assessment. Thus children and adolescents with ASD had the chance to meet me and feel comfortable and safe around me. During the actual assessment, if I noticed that any of the children did not wish to complete the session I immediately ceased the procedure.

### 2.5.3. Study Procedure

The present study was approved by the University of Greenwich's Research Ethics Committee. This study adopted both a cross-sectional and longitudinal approach, following a subsample of children of the initial sample over one year period. During this time there were two assessment phases. The first phase of this study was carried out from April 2015 to December 2015 while the second phase took place from March 2016 to June 2016 where 37 children with ASD and 45 typically developing peers (7-12 years) from the first study were followed up after one year period. It was decided to focus on following up the youngest ASD group in the longitudinal study as crucial developmental changes are suggested to occur during that period (Eccles, 1999). Both assessment phases were scheduled for times during the school year that enabled the teaching staff and students to have sufficient time to participate. This was discussed with individual schools when scheduling assessment points. Data collection lasted no more than 10 to 15 days per school. Before the study began the researcher was introduced to the children involved in the study by a teacher so that the children would become familiarised with the researcher and feel more comfortable with her.

At the start of the first phase the two questionnaires (BRIEF and Vineland) were distributed to the relevant teachers and teaching assistants along with a letter specifying the deadline by which they needed to be returned. The name of the child each questionnaire referred to was written on the top of the questionnaires that were sent out to teaching staff. Teaching staff were given approximately three weeks to complete the questionnaires in their own time. The researcher then emailed these teachers kindly asking them to return the questionnaires either by post or arrange a collection date. Once the questionnaires had been collected the researcher removed the child's name from the questionnaire and replaced it with a personal ID code so that the questionnaires were anonymous. Only the researcher had a copy of the list of names and corresponding ID codes. This was an electronic file that was password protected.

At both assessment phases children completed the tasks individually with the researcher in a quiet room allocated at their school. The tasks were spread over one session that lasted approximately 70 minutes. At the beginning of the session the researcher told the child that she wanted the child's help to play some games. Verbal assent was obtained from each child at the start of every session. If a child did not want to participate then the researcher would collect another child from the class. The child who did not want to participate would be asked on a different day if they would like to participate in the study. During each session the child was reassured that the tasks were just for fun and they had done very well on them. The younger children were given a sticker halfway through the session and another one at the end of the session as a thank you for taking part in the tasks. For older children and adolescents chocolates and sweets were used as reinforcements after checking for allergies and obtaining relevant approval by the schools and the carers. Children and adolescents with ASD find food rewards a very strong reinforcement (Charlop et al., 1990). If the child wanted to stop a session at any point then they were allowed to do so.

At both phases the tasks were presented in the same order to all children. Both sessions allowed children to have a short break in the between if needed. In the first part children completed the WASI, the Reading the Mind in the Eyes test, the Sandbox task, the Tower of London and the Digit Span. In the second part of the session, children completed the Go/No-Go, the IOWA gambling task, and the Delay Discounting task. Debrief sheets were distributed to teaching staff and to children/adolescents to take home on completion of the study.

### 2.6. Pilot Study

A pilot study was carried out prior to the main study. The aim of the pilot study was to ensure that the tasks were at the appropriate developmental level. Ten children were randomly allocated to the pilot study to ensure the designed games were understood and developmentally appropriate for the age range in order to avoid either floor or ceiling effects. The pilot study was also used to assess the feasibility of the procedure (specifically in terms of timings) and to identify if any alterations or adjustments were required.

#### 2.6.1. Sample and Method of Pilot Study

The pilot study was carried out at two different schools recruited for the main study. The first one was a mainstream primary education school and the second was a special education unit educating both children and adolescents with ASD. Five children from Years 2 to Year 6 were recruited from the first school and five children/adolescents with ASD were recruited from the second school. Children were between 7 and 16 years of age. Only the children with ASD who participated in the pilot study formed part of the sample in the final main study due to considerable difficulties finding sufficient numbers of ASD participants. The teachers and teaching assistants of the children in the pilot study did not participate at that point.

Before starting the pilot study the researcher was introduced to the children by a teacher to help the children feel more comfortable with the researcher. Each child took part in a single assessment session. The 70 mins session was divided into two parts allowing children to have a short break in the between (after the first half an hour). In the first part children completed the WASI, the Reading the Mind in the Eyes test, the Sandbox task, the Tower of London and the Digit Span. In the second part of the session, children completed the Go/No-Go, the IOWA gambling task, and the Delay Discounting task.

### 2.6.2. Outcomes of Pilot Study

The pilot study revealed that two parts session was sufficient. However, two children with ASD complained that it was still long and hard to follow after a certain point. This issue was raised and discussed with relevant teaching staff, however they expressed a preference for pupils with ASD not be taken out of class more than twice because they tend to be very distracted when they return to lessons. For the rest of the children, they appeared to find the length of the sessions manageable. Being introduced to the children by a teacher worked well in helping the children feel more comfortable working with the researcher. There were no issues with any of the tasks. The order of the given tasks seemed to work well and was kept for the main study as well. However, the pilot study did highlight a few issues with the delay discounting and Tower of London task.

### 2.6.3. Modifications to Tower of London Task

Typically developing children at the lower end of the age range (7 years old) and children/adolescents with ASD found learning and following the rules of the Tower of London task difficult during the pilot study. More specifically, children with ASD appeared to struggle with the rule of only removing one bead from a peg at a time. To address this problem it was decided that the demonstration of the rules would be longer and that children with ASD would be given two 2-move problems as a practice in order for them to become familiar with the moving of the beads. In addition, some of the children often started trying to solve the problem before the researcher had completed the construction of the problem on their board. To address this issue the researcher emphasised at the beginning of the task that the child had to wait until the researcher said they could start. Finally, another issue about the ToL that emerged in the pilot study was that it was not possible to reliably record initiation time without filming children completing the task. Initiation time was therefore not included as a measure of performance in the main study. These modifications were tested with the additional children. Children were able to grasp the rules of the task more easily with these modifications.

### 2.6.4. Modifications to Delay Discounting Task

Several typically developing children as well as the majority of children with ASD participating in the pilot study found the Delay Discounting task too long. The original task included 110 questions about different amounts of money available after different time delays such as “Would you rather have £10 for sure in 30 days or £2 for sure right now?” Young participants and participants with ASD complained that the game was unnecessarily lengthy and repetitive after some point. The researcher noticed that especially children with ASD would lose interest quite quickly and would randomly choose either A or B on the last block of questions. Thus, it was decided to slightly modify the game and decrease the number of questions from 110 to 70. The new number of questions was tested and was considered to be both accurate in recording children’s performance and feasibly long for them to cope with.

## 2.7. Statistical Analysis

Data were incomplete for some children due to unforeseen circumstances (e.g., absence due to illness) and technical difficulties (e.g., laptop shut down due to power outage). For each group and each dependent measure, extreme scores (outliers) were not identified. Extreme scores were defined as outliers if they were more than three standard deviations from the upper or lower edge of each measure. For the present study, data analysis techniques included Multivariate Analyses of Variance (MANOVAS), Analyses of Variance (ANOVAS), correlational analyses, regression analyses, and the developmental trajectory approach (Thomas et al., 2009).

### 2.8. Summary of the chapter

This chapter presented and discussed the methods and procedures used in the present study. Details about the scope and purpose of each of the measures used were analysed along with a comprehensive description of the research participants and research design followed. A total of 170 children and adolescents participated in this study; 91 typically developing and 79 with ASD. Both males and females were included in this study. Participants were recruited from primary and secondary mainstream schools as well as special education schools. Schools were located in London, Greater London, Surrey and Kent. The researcher used both a cross-sectional and longitudinal design following a subsample of the young children with and without ASD after a period one year. A pilot study was conducted March 2015 and the actual assessment commenced April 2015. This study compared group differences on EF abilities, ToM abilities, adaptive skills and teacher ratings of “real-life” EF. All the tasks employed in the present study were widely used and well validated in developmental studies of both typically developing children and children with ASD. Participants were tested across one session in their school after obtaining written consent from their families. The study was conducted in compliance with the requirements of the Ethics Research Committee of the University of Greenwich.

# CHAPTER III

## Study 1. HOT AND COOL EXECUTIVE FUNCTION AND ITS RELATION TO THEORY OF MIND IN CHILDREN WITH AND WITHOUT AUTISM SPECTRUM DISORDER

**Based on:** Kouklari, E. C., Thompson, T., Monks, C. P., & Tsermentseli, S. (2017). Hot and cool executive function and its relation to theory of mind in children with and without autism spectrum disorder. *Journal of Cognition and Development, 18*(4), 399-418. http://dx.doi.org/10.1080/15248372.2017.1339708

**Abstract**

Previous research has clearly demonstrated that ASD involves deficits in multiple neuropsychological functions, such as EF and ToM. A conceptual distinction is commonly made between cool and hot EF. In ASD, continued attention has been paid to the cool areas of executive dysfunction. Cool EF has been strongly related to ToM but research has not taken into account the association between hot EF and ToM in ASD. The present study investigated the associations between hot and cool EF and ToM in 56 school-aged children (7-12 years) with ASD and 69 controls on tasks tapping cool EF (i.e. working memory, inhibition, planning), hot EF (i.e. affective decision making, delay discounting), and ToM (i.e. mental state/ emotion recognition and false belief). Significant group differences in each EF measure support an executive dysfunction in both domains in ASD. Strong associations between delay discounting and ToM mental state/ emotion recognition are reported suggesting that hot EF makes a unique contribution to ToM above and beyond cool EF in typical development and ASD.  This study improves understanding of the profile of higher-order cognitive deficits in children with ASD.

**Chapter Overview**

This chapter presents Study One which included data from the first time point of the longitudinal study. The following study examines the unique contribution of cool and hot EF to ToM abilities in school-aged children (7-12 years; middle childhood) with and without ASD.

## 3.1. Introduction

Cross-sectional studies of children and adolescents with ASD have consistently revealed significant deficits in cool EF compared to typically developing peers (see Hill's (2004) and Demetriou et al.'s (2017) reviews). Research into hot EF deficits among participants with ASD is relatively scarce and has mainly focused on older adolescents and adults. The extent to which both hot and cool EF are affected in ASD is difficult to determine from the existing literature, as no study to date has addressed the levels of both hot and cool EF in school-aged children with ASD. Proponents of the executive dysfunction theory of ASD claim that the symptoms manifested within the spectrum arise from early EF disruptions (Pennington, & Ozonoff, 1996; Russell, 1997; Russo et al., 2007), and that these are likely to have substantial indirect effects on ToM. This study presents an empirical investigation that aims to expand on the executive functioning of children with ASD and to further explore the link between ToM and EF in children with and without ASD in middle childhood.

Less is known about the EF-ToM relation in school-aged children with and without ASD. Theoretically, it could be possible that EF and ToM are intertwined only in early childhood when both abilities emerge, with EF scaffolding the emergence of ToM mechanisms (Bock, Gallaway & Hund, 2015) as shown by relevant studies (Carlson, & Moses, 2001; Sabbagh et al., 2006). A recent meta-analysis in typical development by Devine and Hughes (2014) has indeed shown a moderate association between cool EF (working memory, planning, inhibition, and cognitive flexibility), selective hot EF aspects (delay of gratification) and ToM false belief in early childhood. As this theoretical account does not explain potential EF-ToM relations later in development, (i.e. middle childhood), another theoretical position suggests that EF and ToM are "inextricably linked" across the life span as both abilities interrelate through "cognitive competencies and performance factors" (share overlapping peripheral task demands) (Bock et al., 2015). The study of the EF-ToM relation beyond the preschool period has recently received growing attention with results showing significant correlations in typical development (Austin et al., 2014; Bock et al., 2015; Im-Bolter, Agostino, & Owens-Jaffray, 2016) but has mainly focused on cool EF aspects.

Evidence regarding the relationship between EF and ToM in ASD is limited and has employed only cool EF aspects. Significant EF-ToM associations have been found both in the preschool period (Pellicano, 2007, 2010) as well as middle childhood (Joseph & Tager-Flusberg, 2004; Ozonoff et al., 1991) in ASD. Despite hot EF being controlled by the ventromedial and orbitofrontal regions which are suggested to also regulate social behaviour (i.e. ToM) (Chan et al., 2008; McDonald, 2013), there is no study in ASD to date which has investigated whether hot EF and ToM share such a significant relation and how they may interact within the cognitive profile of school-aged children with ASD. Due to minimal knowledge regarding the hot EF-ToM relation, this study is exploratory and specific predictions about such relation cannot be stated. The present study will enhance our understanding of the higher-order cognitive deficits that underpin social cognition problems (such as ToM deficits) in ASD.

***Current Study***

The current study had two main objectives:

The first aimed to investigate group differences in hot and cool EF in school-aged children with ASD relative to typically developing peers. Research on EF deficits in ASD has mainly focused on cool EF, failing to address hot EF measures. Thus, the current study sought to extend the investigation of EF differences between school-aged children with and without ASD by employing a more extensive battery of both cool and hot EF tasks in comparison to previous studies (Bock et al., 2015; Geurts et al., 2014). The hot and cool EF model could shed more light on the cognitive profiles of intact and impaired EF abilities in ASD. Moreover, as the limited research on hot EF in ASD has mainly focused on early adolescence and adulthood (Antrop et al., 2006; Demurie et al., 2012; Faja et al., 2013), the present study explored group differences in both cool and hot EF in school-aged children addressing the age gap in the literature. It was hypothesised that ASD participants would exhibit a poorer performance on tests of cool EF. It was sought to determine whether participants with ASD, in contrast to controls, would exhibit a lower level of performance on hot EF measures as well.

The second aim of the present study was to explore the association between hot and cool EF and ToM abilities in school-aged children with and without ASD. School age (middle childhood and early adolescence; 7-12/13 years) is a crucial period of rapid developmental and cognitive change where children have to define and understand both their own sense of self and their sense of others (Siegel, 2013). Thus despite the significant evidence from early childhood, the extension of the EF-ToM relation to school age needs to be examined further in order to provide a solid ground for future longitudinal (such the one to follow on the next chapter) and training studies that could more precisely identify the underlying mechanisms linking EF and ToM. Traditionally, research on the EF-ToM relation has mainly employed cool EF tasks. The distinction between cool (cognitive) and hot (affective) EF led Zelazo et al. (2005) to suggest that ToM may be more strongly related to hot EF than cool EF. Based on evidence from early childhood (Devine, & Hughes, 2014), it was hypothesised that hot EF would still associate with ToM in school age and attempted to specifically examine whether ToM performance could be predicted by hot EF performance after controlling for potential co-variates and cool EF in children with and without ASD.

## 3.2. Method

### *3.2.1 Participants*

Fifty six children (56) with an official diagnosis of ASD (*M*=9.98 years, *SD*=1.9) and sixty nine (69) controls (*M*=9.64 years, *SD*=1.58) aged 7-12 years old participated in the present study. All ASD participants were high functioning (IQ > 70), held an official clinical diagnosis by a qualified clinician using DSM-IV (American Psychiatric Association, 1994) or DSM-V (American Psychiatric Association, 2013) criteria and qualified for a "broad ASD" on the Autism Diagnostic Interview/Autism Diagnostic Interview-Revised (ADI/ADI-R; Le Couteur et al., 1989; Lord, Rutter, & Le Couteur, 1994) and/or the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, DiLavore, & Risi, 2000) , in accordance to National Institute for Health and Clinical Excellence (NICE, 2011) guidelines. They were also in receipt of a Statement of Special Educational Needs (SEN), a legal document that details the child's needs and services that the local authority has a duty to provide, which specified ASD as their primary need. All clinical records were inspected and any individual lacking detailed information about the official source of diagnosis was excluded from the study. No separate research diagnosis using a diagnostic instrument was carried out as there is high degree of agreement between clinical and research diagnosis (Mazefsky & Oswald, 2006). Additional exclusion criteria for the ASD group included the presence of a diagnosed psychiatric illness, comorbid conditions (i.e. seizures or colour blindness) and Full Scale Intelligence Quotient (FSIQ) below 70 as determined by the abbreviated version of the Wechsler Intelligence scales (two subtests: vocabulary and matrix reasoning; Wechsler, 1999). Sixty nine typically developing children were recruited from mainstream primary schools (Years 2-Years 6). Typically developing participants were required to have no diagnosis, and no family history of ASD or other mental health disorders, dyslexia or learning disability. Participants were matched for chronological age ($t\ (123) = -1.1$, $p = .29$) and FSIQ ($t\ (123) = .8$, $p = .42$). Ethical approval for the study was obtained and all participants' parents/carers gave written informed consent (consistent with the Declaration of Helsinki) in compliance to the University Research Ethics Committee. Table 3.1 shows descriptive characteristics (means and standard deviations) of participants of both groups.

Table 3.1. Participants' characteristics

| | Group | |
|---|---|---|
| | ASD | Control |
| Variable | (*n*=56) | (*n*=69) |
| Age (in years) | | |
| *M (SD)* | 9.98 (1.9) | 9.64 (1.58) |
| Range | 7-12 | 7-12 |
| FSIQ total score | | |
| *M (SD)* | 96.73 (16.16) | 99.91 (14.24) |
| Range | 70-121 | 72-129 |

### ***3.2.2. Measures***

A detailed description of the measures is provided in the methodology chapter (Chapter II).

*Cool Executive Function*

***Inhibition***. The 'R' and 'P' version of the Go/No-Go paradigm (Mueller, & Piper, 2014) was used in the present study to assess participants' response inhibition. Participants' response inhibition was measured by recording the proportion of incorrect No-Go trials. Lower scores indicated better performance.

***Planning***. Participants' planning ability was measured by the Tower of London (ToL) task (Shallice, 1982). The number of problems each participant completed successfully was measured. One point was given to participants if they completed the problem successfully and 0 points if they failed to complete the problem. Scores ranged from 0 to 12.

***Working Memory***. The digit span forward and backwards subtests from the Wechsler Intelligence Scale for Children-3rd edition were employed to measure participants' verbal working memory (WISC-III; Wechsler, 1991). Participants were awarded 1 point for each correct trial and the task was terminated when the participant failed both trials at any given span length. The sum of the points awarded for both the forward and backward subtest created a working memory score which was then converted into a standardised score.

*Hot Executive Function*

***Affective Decision Making***. A modified computerised version of the IOWA gambling task (IGT; Bechara et al., 1994) was employed to measure participants' affective decision making. Whether participants made mainly more advantageous or disadvantageous decisions was measured. Based on the approach used by Verdejo-Garcia et al. (2006), scores were calculated by subtracting the number of disadvantageous choices (decks A and B) from the number of advantageous choices (decks C and D) divided then by the total number (n= 100) of trials.

***Delay Discounting***. In line with previous research studying hot EF (Hongwanishkul et al., 2005; Prencipe et al., 2011), the Delay Discounting task was used in the present study in a computerised version to assess participants' ability to discount rewards (Richards et al., 1999). In terms of scoring we followed the procedure described in Myerson et al. (2001), where the indifference points were used to estimate delay discounting. Thus, indifference points were established within participants and were plotted against time (delay). Indifference points and delays were normalised, by expressing indifference points as proportions of the amount of the maximum delayed reward (£10) and the delays as proportions of the maximum delay (365 days). These normalised values were used as the x (delay) and y (indifference points) axes in order to plot the discounting function. Separate trapezoids were then created by drawing vertical lines from each data point on the x axis. The formula $(x_2\text{-}x_1) \cdot [(y_1 + y_2)/2]$ was used to calculate the area of each trapezoid. The areas under these discounting curves (AUC) were calculated by summing the resulting trapezoids.

*Theory of Mind*

***False belief***. In order to measure participants' false belief understanding, the Sandbox Task (Begeer et al., 2012) was used. In terms of scoring, the difference between the original hiding location of the flower bulb (0 cm) and the location where participants indicated dad would look for it was measured (in centimetres). If participants indicated a location towards the direction of Sanne's hiding location of the flower bulb (6,3 cm) they received a positive bias score. If participants indicated a location in the opposite direction of the flower bulb, to the right of the original hiding location, they received a negative bias score. Lower scores indicated better performance.

***Mental state/ emotion recognition.*** The Reading the Mind in the Eyes test (children's version; Baron-Cohen et al., 2001) was used to assess mental state/ emotion recognition. This task was chosen as it is a widely used ToM test that measures the ability to decode the feelings and thoughts of others from the eyes. Successful performance required participants to select the correct mental and emotional state. One point was given to each correctly reported response.

### 3.2.3. Statistical Analysis

Statistical analyses were performed using SPSS-23®. Variables were checked for normality and homogeneity assumptions of parametric tests. No outliers were found. Multivariate analysis of covariance (MANCOVA; adjusted for age and FSIQ) and follow up ANCOVAs (adjusted for age and FSIQ) were conducted to perform between-group comparisons. Pearson's correlations were performed to examine the preliminary relation between EF and ToM measures within the whole sample. Finally, the extent to which hot EF scores would show a unique contribution to ToM independent of ASD and above and beyond the cool EF and control variables (FSIQ and age) was investigated by performing linear hierarchical regression analysis, with cool EF *(go/no-go, digit span, ToL scores)*, control variables (*age & FSIQ*) and ASD diagnosis entered in Block 1, and hot EF variables *(delay discounting* and *IGT scores*) entered in Block 2. In addition, it was examined whether the association of hot EF variables to ToM was stronger in either controls or ASD, by including hot EF X ASD diagnosis interaction terms in Block 3, computed from the cross-product of effect-coded ASD (-1=Autistic, +1=Control) and the centred hot EF scores (Aiken and West, 1991). A small amount of missing data was evident for variables to be examined in the regression analysis (<2.5% for all variables) with missing values imputed using expectation maximisation estimation. No violations of multivariate assumptions for these variables were found. All tests were two-tailed and statistical significance was set at $p < .05$.

## 3.3. Results

### *3.3.1. Group Differences*

Multivariate analysis of covariance (MANCOVA) showed that the performance of the ASD group on EF measures was poorer overall than that of the control group ($\lambda = .69$, $F$ (5, 109) = 9.47, $p < .001$, $\eta^2 = .3$). Follow up ANCOVAs revealed significant group differences in participants' performances both on cool EF: Go/No-Go ($F$ (3, 121) = 15.72, $p < .001$, $\eta^2 = .12$, $d = 0.72$), Digit Span ($F$ (3, 123) = 26.46, $p < .001$, $\eta^2 = .18$, $d = 0.93$), ToL ($F$ (3, 122) = 5. 73, $p = .018$, $\eta^2 = .05$, $d = 0.43$) and hot EF tasks: IGT ($F$ (3, 122) = 5.48, $p = .021$, $\eta^2 = .04$, $d = 0.42$) and delay discounting ($F$ (3, 121) = 11.44, $p = .001$, $\eta^2 = .09$, $d = 0.61$) (see Table 3.2 for means, standard deviations). The ASD group performed significantly worse in each hot and cool EF task relative to the control group.

ANCOVAs were also run to investigate group differences on the ToM measures. Significant group effects were found both in the false belief measure $F$ (3, 121) = 45.39, $p < .001$, $\eta^2 = .28$, $d = 1.22$) and Eyes Test ($F$ (3, 123) = 49.67, $p < .001$, $\eta^2 = .29$, $d = 1.28$). ToM skills of participants with ASD were significantly lower than the typically developing peers (see Table 3.2 for means and standard deviations). The ASD group's performance was significantly lower in both ToM tasks compared to the control group.

Table 3.2. Descriptive statistics for EF and ToM measures.

| | Group | | | |
|---|---|---|---|---|
| | ASD ($n$ = 56) | Control ($n$ = 69) | | |
| Domain and Measure | *M (SD)* | *M (SD)* | $p$ value | *d* |
| Cool EF | | | | |
| Digit Span | 7.36 (2.64) | 9.91 (2.90) | <.001 | 0.93 |
| Go/No go | 50.80 (15.02) | 37.93 (20.34) | <.001 | 0.72 |
| ToL | 7.07 (2.11) | 7.85 (1.93) | .018 | 0.43 |
| Hot EF | | | | |
| IGT | -.05 (.18) | .03 (.20) | .021 | 0.42 |
| Delay Discounting | .33 (.21) | .44 (.12) | .001 | 0.61 |
| ToM | | | | |
| False belief | 6.4 (3.62) | 3.29 (1.23) | <.001 | 1.22 |
| EyesTest | 14.87 (3.36) | 18.41 (2.45) | <.001 | 1.28 |

Note. *d*: Cohen's d effect size.

### *3.3.2. Relations between EF and ToM*

Correlational analysis in the whole sample (see Table 3.3) showed several significant associations between EF and ToM measures. Specifically, ToM false belief performance was significantly correlated to all cool EF measures and hot Delay Discounting, whereas performance on the Eyes Test was related to all EF measures, both cool and hot. Supplementary correlational analysis partialling out the effects of control variables (age and FSIQ) was conducted again. The ToM false belief measure remained significantly related to all cool EF and hot Delay Discounting, whereas the Eyes Test remained significantly associated only with Digit Span, Go/No-Go, and Delay Discounting (see table 3.3).

Table 3.3. Pearson's Correlation Coefficients among ToM and EF variables.

| **Measures** | FSIQ | Age | DigitSpan | ToL | Go/No-Go | IGT | Discounting | FalseBelief | EyesTest |
|---|---|---|---|---|---|---|---|---|---|
| FSIQ | | -.43** | .22* | .23** | -.05 | .15 | .05 | -.19* | .30** |
| Age | | | -.001 | .22* | -.09 | -.04 | .02 | -.03 | .01 |
| DigitSpan | | | | .37** | -.17 | .26** | .19* | -.32** | .26** |
| ToL | | | | | -.06 | .11 | .10 | -.29** | .30** |
| Go/No-Go | | | | | | -.20* | -.02 | .26** | -.33** |
| IGT | | | | | | | .09 | -.17 | .22* |
| Discounting | | | | | | | | .22* | -.32** |
| FalseBelief | | | | | | | | | -.42** |

| Control for: Age & FSIQ | DigitSpan | ToL | Go/No-Go | IGT | Discounting | FalseBelief | EyesTest |
|---|---|---|---|---|---|---|---|
| DigitSpan | | .32** | -.15 | .23 | .19 | -.28** | .19* |
| ToL | | | .001 | .07 | .07 | -.23* | .18 |
| Go/No-Go | | | | -.19* | -.01 | .24** | -.33** |
| IGT | | | | | .09 | -.14 | .18 |
| Discounting | | | | | | .21* | -.32** |
| FalseBelief | | | | | | | -.37** |

Note. *p <. 05, **p < .01. *FSIQ*: Full Scale Intelligence Quotient, *ToL*: Tower of London, *IGT*: Iowa Gambling Task, *Discounting*: Delay Discounting, *Eyes Test*: Reading the Mind in the Eyes

The relation between EF and ToM was further investigated by running two hierarchical multiple regression analyses in order to assess the extent to which hot EF scores predicted ToM (*false belief* and *Eyes Test scores*) independent of ASD diagnosis and over and above cool EF as well as control variables (age & FSIQ), and to examine whether the association between hot EF and ToM was stronger in ASD participants compared to controls. Dependent variables included the Eyes Test and false belief measures.

Full results of the hierarchical regression analysis are presented in Table 3.4. These show that the first block introducing age, FSIQ, cool EF and ASD contributed significantly to the variance of the ToM false belief ability, $F$ (6, 118) = 9.99, $p$ < .001, explaining 34% of the variance. However, neither block 2 variables of Hot EF scores nor block 3 variables of Hot EF X ASD diagnosis interaction terms contributed significant additional variance.

Regarding ToM mental state/ emotion recognition, control variables, ASD and cool EF explained 39.2% of the variance in Eyes Test scores [$F$ (6, 118) = 12.70, $p$ < .001]. For hot EF variables entered in block 2, the total variance explained rose to 42.7%, representing a significant increase of 3.4% [$F$ (2, 116) = 3.48, $p$ =.034] additional variance explained. The Hot EF X ASD interaction terms entered in block 3 explained no significant additional variance. Eyes Test scores were significantly predicted by Go/no Go scores ($p$ = .03), delay discounting ($p$ = .015) and ASD ($p$ < .001).

Table 3.4. Hierarchical regression analysis for ToM false belief and Eyes Test scores by group and EF variables

| Predictors | False belief | | EyesTest | |
|---|---|---|---|---|
| | β | $\Delta R^2$ | β | $\Delta R^2$ |
| *Block 1* | | .34** | | .39** |
| (Control variables, cool EF and ASD) | | | | |
| Age | -.08 | | .14 | |
| FSIQ | -.16 | | .3** | |
| Digit Span | -.04 | | -.07 | |
| Go/No-Go | .05 | | -.16* | |
| ToL | -.14 | | .09 | |
| ASD | .46** | | -.47** | |
| *Block 2* | | .004 | | .03* |
| (Hot EF) | | | | |
| IGT | -.04 | | .07 | |
| Delay discounting | .046 | | .18* | |
| *Block 3* | | .03 | | .01 |
| (Hot EF X ASD interactions) | | | | |
| ASD X IGT | -.06 | | -.03 | |
| ASD X Delaydiscounting | -.03 | | -.12 | |
| $R^2$ | | .37 | | .44 |

| | | |
|---|---|---|
| *F* test | 2.61 | 1.19 |

Note. *p <. 05, **p < .01.

### 3.4. Discussion

This study compared a relatively large group of school-aged children (in middle childhood) with ASD to typically developing peers using a number of cool and hot EF tasks. It also investigated the relation between both EF constructs and ToM in school-aged children with and without ASD. Participants with ASD demonstrated poorer performance in all EF and ToM domains suggesting that the reported group differences reflect a universal ToM and EF impairment in both hot and cool systems in ASD. Furthermore, these findings not only replicated the well-established relation between cool EF and ToM but also demonstrated a predictive relation between hot EF (delay discounting) and ToM mental state/ emotion recognition, prompting questions of how these seemingly distinct constructs are related. This is the first study to date to report that a hot EF aspect is a significant predictor of ToM mental state/ emotion recognition above and beyond cool EF in school age and that children with ASD exhibit hot EF impairment, which are likely to contribute to their deficits in ToM.

School-aged children with ASD presented significant impairments in each hot and cool EF task relative to matched typically developing children of the same age. The present findings of deficits in cool EF are consistent with results of previous studies reporting deficits in working memory (Alloway et al., 2009; Geurts et al., 2014a), planning (Geurts et al., 2014a; Hill, 2004) and response inhibition (Hill, 2004; van Eylen et al., 2015) in participants with ASD of the same age range. There is thus clear evidence that individuals with ASD experience deficits in cool EF domains.

In terms of hot affective decision making, results are in line with previous studies (De Martino et al., 2008; Yechiam et al., 2010) that have demonstrated deficits in adolescents and young adults with ASD and further extend this to a younger age ASD group. The larger sample size and different IQ level of the ASD participants in the present study could have possibly accounted for the results that contradicted those of Johnson et al.'s (2006), Faja et al.'s (2013), and South et al.'s (2014) studies, despite the IGT also being used. The limited sample sizes (Johnson et al., *n=29*; Faja et al., *n=40*) do not usually allow for the detection of significant differences while the superior IQ scores (10 points higher) of South et al.'s (2014) participants could possibly explain discrepancies in findings. These inconsistencies though highlight the need for future studies investigating affective decision making in school-aged children with ASD.

Regarding the ASD deficits found in hot delay discounting, results are not consistent with those of Antrop et al. (2006) and Demurie et al. (2012) who found that ADHD school-aged children, but not school-aged children with ASD, chose smaller, immediate rewards over large delayed rewards more than the control group. Results contradicting Demurie et al. (2012) were quite surprising, as these researchers also employed a similar age range of ASD participants (8-16 years). However, their delay discounting task addressed much higher reward magnitudes (such as 0€, 5€, 10€, 20€ and 30€) and shorter delay values (i.e. now, tomorrow, the day after tomorrow, 1 week, 2 weeks) than in the present task. It seems that the discounting rate is a decreasing function of the size of the delayed reward (rate decrease as the amounts offered increase) (Kirby, & Maracovic, 1996). Antrop et al. (2006) used a less demanding task where participants had to choose between an immediate small reward (1 point) after a 2-second delay and a larger delayed reward (2 points) after a 30-second delay. Thus participants with ASD may exhibit responses similar to control group discounting trajectories if the monetary rewards are significantly high or the time delays are very short in magnitude. These results support an impairment in both hot and cool EF systems across school age in ASD expanding the executive dysfunction to not only cool EF but hot processes such as affective decision making and delay discounting as well.

With regards to ToM deficits, the reported impairments in false belief skills are consistent with previous findings showing deficits in such skills in young children with ASD (Kimhi et al., 2014; Pellicano, 2007) and indicate that ToM difficulties persist in school-aged children with ASD. In relation to ToM mental state/ emotion recognition, results revealed that participants with ASD presented significant differences relative to the control group and contradict a previous study that assessed ToM using mental state/ emotion recognition scores in pre-school children with ASD (Kimhi et al., 2014). More specifically, Kimhi et al. (2014) showed that pre-school children with ASD (age: 5 years) performed successfully in tasks requiring recognition of basic emotions (happy/sad) relative to the control group. The Reading the Mind in the Eyes test used here assesses a more sophisticated ability, namely to recognise or infer another's emotional mental state. Such ability is fundamental to understanding and effectively communicating with other people when interacting socially. The present results indicated that this ability is impaired in school-aged children with ASD and are in line with previous research (Golan et al., 2007; Rieffe et al., 2000) suggesting that the emotion recognition of children with ASD is disrupted when processing high-order, complex or atypical emotions.

The present correlational and regression analysis results showed that EF and ToM are strongly associated in school age beyond their emergence in early childhood. In line with previous studies showing cool EF-ToM associations in young and school-aged children with and without ASD (Carlson, & Moses, 2001; Pellicano, 2007; Kimhi et al., 2014; Ozonoff et al., 1991), it was found that ToM mental state/ emotion recognition was predicted by cool EF (inhibition) overall. Participants who performed better in the inhibition task could more easily disengage from their own emotional states or suppress irrelevant ones, and subsequently infer advanced empathising skills for another's emotion. During middle childhood (7-11/12) children are in greater need of their EF abilities when facing advanced forms of knowledge and widening social horizons through sophisticated social interactions with peers (Del Giudice, 2014). These results indeed show that in ToM thinking across school age it seems necessary to *inhibit* one's own perspective when socially interacting, in order to infer all the relevant interactive pieces into a coherent framework.

These findings confirm earlier research suggesting that hot EF does indeed relate to ToM performance. The hot EF aspect of delay discounting predicted ToM mental state/ emotion recognition over and above cool EF and control variables in school-aged children with and without ASD. ToM is a multifaceted function involving not only beliefs, desires and emotions but also processes associated with the successful management of long-term goals (Korkmaz, 2011). Thus, the capacity to disengage from the present while considering more long-term goals could associate with the way one engages with emotional states. Stolarski et al. (2011) suggest that emotional functioning plays an important role in the development of a temporal perspective. For instance, the ability to balance decisions and their future consequences is associated with mental state/ emotion recognition ability in the sense that effective emotional functioning allows for more effective balancing between temporal perspectives. Delay discounting is a fundamental aspect of future temporal perspective taking and plays an important role in the development of future-oriented behaviours (Zimbardo, & Boyd, 2008). This could also explain the significant associations between individual differences in delay discounting and mental state/ emotion recognition. Delay discounting engages not only decisional processes but also affective emotional mechanisms, raising the need to empirically investigate how discounting rate is actually linked to emotional functioning across the lifespan in typical development and ASD.

It should be noted that the hot EF x ASD interaction contributed no significant additional variance as generally interactions are notoriously underpowered for observational data (i.e. usually non-significant in all but very big samples); thus a more rigorous examination of any hot EF x ASD interaction would require a larger sample size. However, hot EF was associated to ToM impairment above and beyond any influence of cool EF, and the ASD participants demonstrated impaired hot EF. This could suggest that hot EF may be a key mechanism underpinning deficits in ToM for high-functioning children with ASD. This finding requires further replication with a larger sample.

This study investigated the associations between hot and cool EF and ToM in school-aged children with and without ASD. The significant group differences in each hot EF task followed by a significant association between hot delay discounting and ToM mental state/ emotion recognition should be considered in light of the limitations of this study. First, although this study provided a more advanced insight into the fractionated hot/cool EF model in ASD, it only included 7 to-12-year-old school-aged participants; hence it remains to be found whether these results could be generalised to younger children, adolescents, and adults across the autism spectrum functioning levels. Second, as the present study was the first to report such a relation, the findings need to be interpreted cautiously. Specifically, as hot EF delay discounting significantly predicted only one of the two ToM measures addressed (Eyes Test), clear conclusions about the role of hot EF to the wider ToM context cannot be drawn. It should be noted that the Reading the Mind in the Eyes test is a task tapping mostly emotion understanding aspects, while the Sandbox task is a more cognitive measure of understanding beliefs. The present results showed that hot EF presented a predictive relation only with the Eyes Test that can be argued to measure a more affective aspect of ToM cognition. The failure to demonstrate a hot EF- Sandbox task association could be cautiously explained in the basis of the underlying affective nature of hot EF by definition, suggesting that hot EF is elicited under motivationally or emotionally significant situations (such as inferring emotional states in the Eyes Test). It could be possible that cognitive and affective ToM are dissociated and that hot ToM might correlate more strongly with hot EF. However, as this issue goes beyond the scope of the present study, it is worth questioning in future research whether these two distinct domains of EF (hot and cool) correspond in reality to separate ToM measures tapping different abilities. Both ToM measures we addressed here tap only particular aspects of ToM (either purely cognitive or affective cognitive) and cannot be considered the only essential ToM measures. Follow-up research should therefore consider investigating such relations addressing several other varied ToM tasks such as second-order ToM (Perner, & Wimmer, 1985), the strange stories (Happé, 1994) or the Faux Pas test (Baron-Cohen et al., 1999). Finally, the exact relation between ToM mental state/ emotion recognition and delay discounting is difficult to determine as the data presented here do not provide evidence about directionality of the relation. In the light of the conceptual framework presented above, mental state/ emotion recognition seems to contribute to the development of temporal dimensions such as delay discounting. On the other hand, the reported regression models revealed that delay discounting predicted ToM mental state/ emotion recognition over and above control variables. The focus on specific temporal dimensions (i.e. delay discounting) may thus influence the development or use of emotional abilities. This unclear directionality will be further investigated by the next study (Study Two-Chapter Four) using a longitudinal approach that could facilitate the understanding of this complex causal relation.

In conclusion, Study One represented a first step towards further understanding the heterogeneity of the neurocognitive impairments in ASD. The consideration of both hot and cool EF and ToM in ASD assessment provided a greater understanding of the higher-order cognitive deficits underlying difficulties with social interaction for the ASD population. This study demonstrated a clear ToM and EF impairment in both hot and cool systems in ASD and increased understanding of the association both hot and cool EF share with selective ToM mechanisms in school-aged children with and without ASD. As the present study was cross-sectional and attempting to identify the potential role of hot EF in ToM in middle childhood, no information about the nature and the directionality of the functional relation between EF and ToM was revealed. The next study, Study Two aimed to expand on the findings of Study One by exploring the longitudinal associations between the developmental patterns of EF and ToM across middle childhood (over a year). Thus, Study Two will build on Study One by investigating whether developmental changes in EF predict later ToM changes over a year or vice versa. Such data may provide a greater understanding of the functional link between these crucial cognitive constructs as well as of the conceptualisation of these overlapping yet separate constructs.

# Chapter IV

## Study 2. DEVELOPMENTAL TRENDS OF HOT AND COOL EXECUTIVE FUNCTION IN SCHOOL-AGED CHILDREN WITH AND WITHOUT AUTISM SPECTRUM DISORDER: LINKS WITH THEORY OF MIND


### Abstract

The present study used a longitudinal design to examine the developmental changes in cool and hot EF of children with ASD (n=45) and matched (to age and IQ) controls (n=37), aged between 7 to 12 years, as well as the impact of EF on ToM development over a year. For children with ASD, although selective cool (working memory, inhibition) and hot (affective decision making) EF domains presented age-related improvements, they never reached the performance level of the control group. Early cool working memory predicted later ToM in both groups but early hot delay discounting predicted later ToM only in the ASD group. No evidence was found for the reverse pattern (early ToM predicting later EF). These findings suggest that improvements in some EF aspects are evident in school age in ASD and highlight the crucial role both cool and hot EF play in ToM development.



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**Chapter Overview.** The present longitudinal study built on Study One by exploring the developmental trends of hot and cool EF and their links to ToM after a year across middle childhood, in school-aged children between 7 and 12 years old with and without ASD. The present study attempted to expand the ToM-EF association presented in the first study by focusing on whether the potential developmental gains of cool and hot EF skills could be linked to the development of ToM across middle childhood. This longitudinal investigation followed up a subsample (n=82) of school-aged children with and without ASD from Study One, a year after the initial assessment.

## 4.1. Introduction

Evidence from both typical development and ASD has consistently shown that EF is not only strongly associated to ToM across childhood (Bock et al., 2015; Carlson et al., 2013; Im-Bolter et al., 2016), but that there is in fact a more fundamental link between EF and ToM; with functioning in one domain being a necessity for the emergence of the other (Perner, 1998; Perner & Lang, 1999; Russell, 1996). Several longitudinal studies on the EF-ToM relationship in early childhood in typical development indicated that children's performance on EF measures predicted later performance on ToM false belief tasks (independent of age, verbal ability, and earlier ToM scores) but not vice versa (Carlson et al., 2004; Flynn, 2007; Hughes, 1998b; Hughes & Ensor, 2007). However, less is known about the extension of this developmental relationship in school-aged children with and without ASD. Relevant longitudinal research in middle childhood in typical development is very limited (e.g. Austin et al., 2014) and has demonstrated weak evidence for the account that early ToM predicts later EF, but stronger support of the early EF influencing later ToM in school age. This could suggest that EF might play a substantial role in children's developmental outcomes, particularly in relation to social cognition. The developmental nature of the EF-ToM relationship in ASD has been vastly theoretically debated due to this coexistence of deficits in both domains. Growing evidence shows that the ASD functional/ social outcomes, such as ToM, may be due to differences in emerging EF abilities (Demetriou et al., 2017; Leung et al., 2016; Pellicano 2012; Russo et al., 2007). The important contribution of EF in typical development, together with these promising findings from studies in ASD provide good reason to suspect that the development of EF might critically influence children's developmental trajectories of sociocognitive profiles, particularly ToM skills (with poor EF being a risk factor for poor developmental outcomes) in ASD.

It should be noted that the determination of the precise nature of the EF developmental pathway and its influence on ToM in ASD first requires research to shed more light on the actual nature of EF itself (Pellicano, 2012). EF development has been mainly assessed by tasks assessing cool EF despite recent evidence supporting separate domains of cool and hot EF (Kim et al., 2014; Willoughby et al., 2011). Generally little is known about the developmental course of "hot"-affective EF processes and whether cool and hot EF present similar developmental changes. The potential differences in the developmental trends of cool and hot EF (e.g. Hooper et al., 2004; Prencipe et al., 2011), as discussed in Chapter One, is an open topic of debate, and such examination in ASD could make it plausible for separate EF domains to be found specifically affected or have specific developmental relations to other outcomes such as ToM. The limited number of longitudinal EF studies in ASD (Griffith, Pennington, Wehner, & Rogers, 1999; Ozonoff & McEvoy, 1994; Pellicano, 2010) have focused only on cool aspects to date and due to mixed results it is not clear whether the development of EF in ASD follows the same pathway as that of typical development. There is no study to date having explored the longitudinal developmental changes of hot EF subcomponents in ASD.

Finally, it should be noted that research into the ToM-EF association in school-aged participants has mainly employed cool EF tasks, despite hot EF and ToM considered as being mediated by the same medial regions of the prefrontal cortex (Chan et al., 2008; McDonald, 2013; Sabbagh et al., 2009). For instance, social interactions that involve ToM abilities may require the control of behaviour or thought under emotionally significant situations (hot EF) (Zelazo & Müller, 2002). Thus, hot EF could be more central to the emergence of ToM. Study Two is the first investigation to date to investigate whether hot EF influences ToM across time and how they may interact within the cognitive profile of school-aged children with ASD.

### *Current Objectives*

Research on the development of hot EF both in typical development and in ASD lags behind that of cool EF. Furthermore, the developmental relationship between EF and ToM has only focused on cool EF aspects; thus the understanding of the potential link between hot EF and ToM is quite limited. Building on Study One that reported the first cross-sectional association between both hot and cool EF and ToM to date, Study Two aimed to explore whether that relation is more than skin deep; if there is a functional link among these cognitive domains across time. Study Two aimed to identify whether the developmental changes of the various, distinct EF skills assessed in Study One provide a platform for the emergence of ToM across middle childhood. As the longitudinal studies investigating such EF- ToM links in middle childhood (> 5 years) are very limited, extending research in this developmental phase is critical in order to examine whether concurrent associations or developmental patterns found in early life persist across the course of children's development (McAlister & Peterson, 2013). Moreover, based on the evidence presented in Chapter One (Hooper et al., 2004; Prencipe et al., 2011), distinct EF domains (hot and cool) are expected to follow different developmental trends and become more specialised across middle childhood and adolescence. Another important reason to assess EF development in school-aged children (middle childhood) is the fact that it is likely that there may be "sleeper effects" in which individual differences/ changes in EF do not present significant effects in early childhood but present (larger) observable effects on social cognition during middle childhood (Best et al., 2009). The present study therefore attempted to address these gaps in the literature.

The first aim of this study was to compare the developmental changes in cool and hot EF and ToM abilities between school-aged children with and without ASD after a one year interval. Taken together, previous studies show there is no clear developmental framework of cool EF in ASD; with some studies reporting age-related improvements (Pellicano, 2010) and others not (Griffith et al., 1999; Ozonoff & McEvoy, 1994). Moreover, no research to date has investigated the development of hot EF in ASD. Due to these mixed findings and the minimal longitudinal evidence regarding the development of hot EF in ASD, the present study was exploratory and specific predictions could not be made. It was sought to determine whether there are similarities or deviance/delay relative to controls in the hot and cool EF developmental pathways followed in ASD.

The second aim was to shed more light on the longitudinal association between cool and hot EF and ToM in school-aged children with and without ASD. Based on previous research, specific predictions can be made only about the cool EF-ToM link, due to the current lack of relevant longitudinal hot EF research. Specifically, there is stronger evidence for the cool EF to predict the emergence of ToM rather than the opposite in early childhood and the preschool period in typical development (Marcovitch et al., 2014) and ASD (Pellicano, 2010, 2012). It was hypothesised that early cool EF would predict later ToM also in school-aged children with and without ASD. Taking into consideration both the theoretical notion that ToM may be more strongly related to hot EF than cool EF (Zelazo et al., 2005) and results of Study One (hot EF predicted ToM cross-sectionally over and above cool EF), it was attempted to explore whether later ToM performance could be also predicted by early hot EF performance after controlling for potential covariates and cool EF. Finally, it was also examined whether the association of hot EF variables to ToM was stronger in either controls or ASD, by including hot EF X ASD diagnosis interaction terms.

## 4.2. Methods

### *4.2.1. Participants*

This longitudinal study includes data from both assessments phases. A subsample of controls and children with ASD from Study One were followed up a year after the initial assessment. More specifically, forty five (45) children with an official diagnosis of ASD (M=9.07 years, SD=1.42) and thirty seven (37) controls (M=9.03 years, SD=1.17) aged 7-12 years old participated in the present study. At the second time point all 82 children were followed up (0% attrition). All controls and ASD participants fulfilled the inclusion criteria for participation as described in Study One. Participants were matched for chronological age ($t$ $(80)$ = -.13, $p$ = .89) and FSIQ ($t$ $(80)$ = 1.73, $p$ = $.09$). Table 4.1 shows descriptive characteristics (means and standard deviations) of participants of both groups.

Table 4.1. Participants' characteristics

| Variable | Group ASD (*n*=45) | Control (*n*=37) |
|---|---|---|
| Age (in years) | | |
| *M (SD)* | 9.07 (1.42) | 9.03 (1.17) |
| Range | 7-12 | 7-12 |
| FSIQ total score | | |
| *M (SD)* | 98.05 (12.13) | 102.11 (14.3) |
| Range | 70-127 | 76-135 |

#### ***4.2.2. Measures***

A detailed description of the measures is given in the methodology chapter (Chapter Two).The same measures of hot and cool EF and ToM presented in Chapter Three (Study One) were used in the present study as well. Cool EF were assessed by measures tapping inhibition, planning and working memory abilities, while hot EF were assessed by tasks of affective decision making and delay discounting abilities. ToM was assessed using a false belief task (Sandbox task) and one of mental state/ emotion recognition task (Reading the Mind in the Eyes test).

### **4.3. Results**

All variables were checked for normality and homogeneity assumptions of parametric tests. No extreme outliers were found. Analyses were conducted at two levels. The developmental changes in cool & hot EF and ToM of children with ASD relative to neurotypical controls across the 12 months were firstly examined. Secondly the predictive relation between hot & cool EF and ToM across the two time points was investigated. No violations of multivariate assumptions for these variables were found. All tests were two-tailed and statistical significance was set at $p < .05$.

### 4.3.1. Comparison of the developmental changes in EF and ToM between the two groups

Table 4.2 presents descriptive statistics for hot & cool EF and ToM at each time point. The developmental changes in children's EF and ToM abilities across time points were examined by carrying out a mixed ANOVA. Time was set as the within-subject factor (T1, T2) and Group as the between-subject factor (ASD or control). Post hoc tests were not performed for Group because there were fewer than three groups. Within group comparisons were assessed by paired sample t-tests.

Table 4.2. Means and standard deviations for variables across the time points.

| | T1 | | | | | | T2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Control | | ASD | | | | Control | | ASD | | |
| | M | (*SD*) | M | (*SD*) | *d* | | M | (*SD*) | M | (*SD*) | *d* |
| Go/No-Go | 36.86 | *(20.46)* | 47.77 | *(16.04)* | 0.6 | | 34.03 | *(17.06)* | 46.59 | *(15.22)* | 0.78 |
| ToL | 7.45 | *(1.58)* | 7.26 | *(2.04)* | -0.1 | | 9.34 | *(1.45)* | 8.69 | *(1.60)* | -0.42 |
| Digit Span | 9.71 | *(2.39)* | 7.18 | *(3.03)* | -0.92 | | 10.47 | *(2.54)* | 9.34 | *(1.66)* | -0.54 |
| IGT | .04 | *(.21)* | -.05 | *(.19)* | -0.45 | | .08 | *(.16)* | .02 | *(.16)* | -0.38 |
| Delay | .36 | *(1.32)* | .42 | *(.20)* | 0.07 | | .38 | *(.17)* | .4 | *(.17)* | 0.12 |
| Sandbox | 2.76 | *(1.04)* | 3.93 | *(2.81)* | 0.5 | | 2.95 | *(1.51)* | 2.85 | *(1.97)* | -0.06 |
| Eyes Test | 18.20 | *(2.81)* | 15.33 | *(3.47)* | -0.9 | | 20.25 | *(2.82)* | 18.6 | *(3.43)* | -0.5 |

Note. *d*: Cohen's d effect size.

**Working memory (digit span).** **S**ignificant main effects of time *F* [(1, 80) = 50.6, p = .001, $\eta_p^2$ = .39] and group [*F* (1, 80) = 13.52, *p* < .001, $\eta_p^2$ = .15] were found. The interaction between time and group was also significant, [*F* (1, 80) = 11.73, *p* = .001, $\eta_p^2$ = .13]. Figure 4.1 presents mean working memory score from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed poorer performance in working memory than neurotypicals both at Time 1, *F* (1, 80) = 17.09, *p* < .001, $\eta_p^2$ = .18, and at Time 2, *F* (1, 80) = 6.24, *p* = .02, $\eta_p^2$ = .07. Further analyses showed that children's performance improved significantly over time in both groups; ASD: *t* (45) = -7.96, *p* < .001; controls: *t* (37) = -2.45, *p* = .019. The significant interaction lays in the pattern of improvements over time. While both groups demonstrated developmental changes after 12 months, improvements for the ASD group were steeper (see figure 4.1). The ASD group demonstrated a poorer performance on digit span scores throughout this developmental period.

**Planning (Tower of London).** The main effect of time [*F* (1, 80) = 86.65, *p* < .001, $\eta_p^2$ = .52], was found significant. Neither the main effect of group, [*F* (1, 80) = 1.58, *p* = .21, $\eta_p^2$ = .2], nor the interaction between time and group, [*F* (1, 80) = 1.67, *p* = .2, $\eta_p^2$ = .02], were found significant. Figure 4.1 presents mean planning score from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed equal performance in planning to neurotypicals both at Time 1, *F* (1, 80) = .21, *p* = .65, $\eta_p^2$ = .003, and at Time 2, *F* (1, 80) = 3.62, *p* = .061, $\eta_p^2$ = .043. Further analyses showed that children's performance improved significantly over time in both groups; ASD: *t* (45) = -7.10, *p* < .001; controls: *t* (37) = -6.14, p < .001. Figure 4.1 reveals the similar developmental improvements after 12 months.

**Inhibition (go/no-go).** The main effect of time on inhibition, [*F* (1, 80) = 14.61, *p* <.001, $\eta_p^2$ = .15], and group [*F* (1, 80) = 9.68, *p* = .003, $\eta_p^2$ = .11], were found significant. No significant interaction between time and group, [*F* (1, 80) = 2.48, *p* = .12, $\eta_p^2$ = .03] was found. Figure 4.1 presents mean inhibition score from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed poorer performance in inhibition than neurotypicals both at Time 1, *F* (1, 80) = 7.32, *p* = .008, $\eta_p^2$ = .08, and at Time 2, *F* (1, 80) = 12.39, *p* = .001, $\eta_p^2$ = .13. Further analyses showed that children's performance improved significantly over time in both groups; ASD: *t* (45) = 4.3, *p* < .001; controls: *t* (37) = 2.52, *p* = .015; Both groups demonstrated developmental performance gains after 12 months but the ASD group demonstrated a poorer performance on the Go/No-Go task throughout this developmental period.

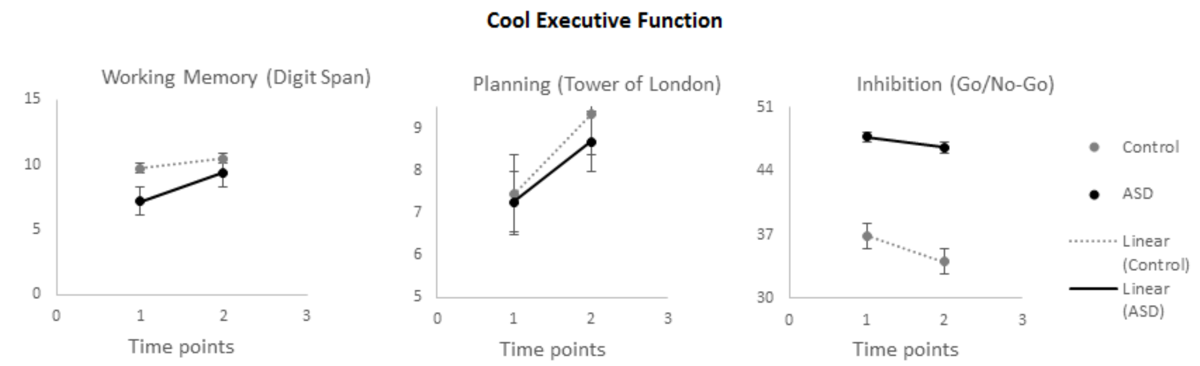


**Figure 4.1. Mean Cool EF scores across 12 months for ASD and control groups.**

**Affective decision making (IOWA).** The main effect of time [$F$ (1, 80) = 17.33, $p$ < .001, $\eta_p^2$ = .18] and group [$F$ (1, 80) = 4.76, $p$ = .03, $\eta_p^2$ = .06] were found to be significant. The interaction between time and group, [$F$ (1, 80) = .46, $p$ = .49, $\eta_p^2$ = .01] was not significant. Figure 4.2 presents mean affective decision making from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed poorer performance in affective decision making than neurotypicals both at Time 1, $F$ (1, 80) = 4.31, $p$ = .041, $\eta_p^2$ = .05, and at Time 2, $F$ (1, 80) = 4.03, $p$ = .048, $\eta_p^2$ = .05. Further analyses showed that children's performance improved significantly over time in both groups; ASD: $t$ (45) = -2.91, $p$ = .006; controls: $t$ (37) = -4.03, $p$ = .001. Figure 4.2 shows that both groups demonstrated developmental performance improvements after 12 months, but with ASD children showing a poorer performance throughout this developmental period.

**Delay discounting (delay discounting task).** The effect of time [$F$ (1, 80) = .09, $p$ = .76, $\eta_p^2$ = .001], group [$F$ (1, 80) = 3.34, $p$ = .071, $\eta_p^2$ = .04], and the interaction between time and group, [$F$ (1, 80) = 1.91, $p$ = .17, $\eta_p^2$ = .02], were not found significant. Figure 4.2 presents mean delay discounting score from T1 to T2 for each group. Planned comparisons demonstrated that the two groups showed equal performance in delay discounting both at Time 1, $F$ (1, 80) = 5.15, $p$ = .06, $\eta_p^2$ = .06, and at Time 2, $F$ (1, 80) = .46, $p$ = .49, $\eta_p^2$ = .006. Further analyses showed that children's performance did not improve significantly over time in either group; ASD: $t$ (45) = 1.41, $p$ = .17; controls: $t$ (37) = -.65, p = .52. Neither group presented developmental changes after 12 months.

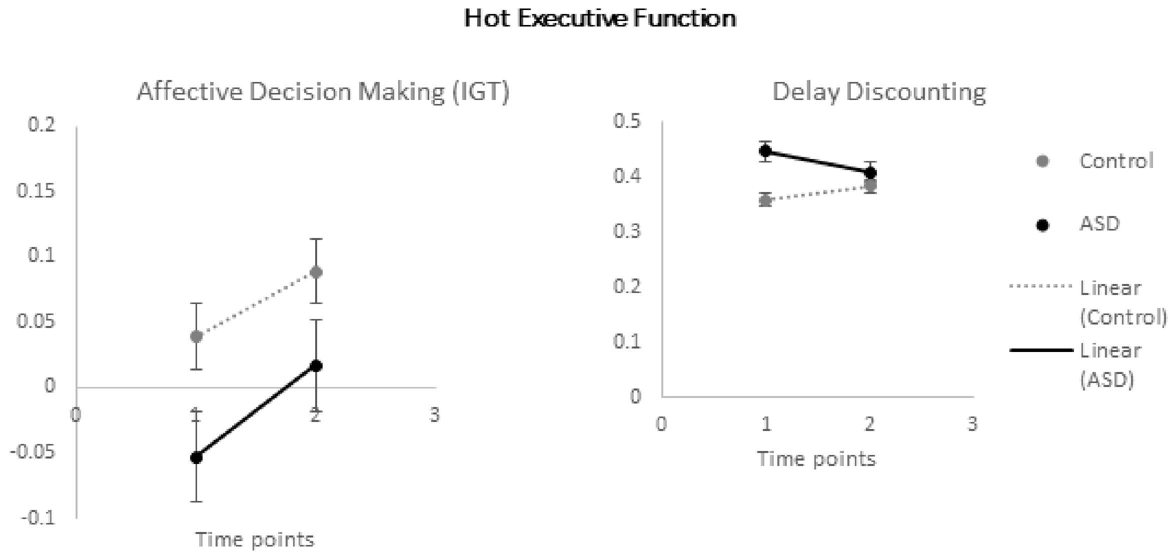


**Figure 4.2**. **Mean Hot EF scores across 12 months for ASD and control groups.**

**False belief (Sandbox).** The main effect of time [$F$ (1, 80) = 4.29, $p$ = .04, $\eta_p^2$ = .05] was found significant. The effect of group [$F$ (1, 80) = 2.12, $p$ = .15, $\eta_p^2$ = .03] was not significant while interaction between time and group, [$F$ (1, 80) = 8.54, $p$ = .005, $\eta_p^2$ = .09] was found significant. Figure 4.3 presents mean false belief score from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed poorer performance in false belief than neurotypicals only at Time 1, $F$ (1, 80) = 6.18, $p$ = .015, $\eta_p^2$ = .07, but equal scores at Time 2, $F$ (1, 80) = .06, $p$ = .8, $\eta_p^2$ = .001. Further analyses showed that children's performance improved significantly over time only in the ASD group; ASD: $t$ (45) = 3.32, $p$ = .002; controls: $t$ (37) = -.69, $p$ = .49. (Higher score indicates worse performance in this task)

**Mental state/ emotion recognition (Reading the Mind in the Eyes).** The main effects of time [$F$ (1, 80) = 92.04, $p$ < .001, $\eta_p^2$ = .54], group [$F$ (1, 80) = 12.13, $p$ = .001, $\eta_p^2$ = .13], and the interaction between time and group, [$F$ (1, 80) = 4.84, $p$ = .03, $\eta_p^2$ = .06] were all found significant. Figure 4.3 presents mean mental state/ emotion recognition score from T1 to T2 for each group. Planned comparisons demonstrated that the ASD group showed poorer performance in mental state/ emotion recognition than neurotypicals both at Time 1, $F$ (1, 80)

= 16.43, $p < .001$, $\eta_p^2 = .17$, and at Time 2, $F$ (1, 80) = 5.52, $p = .021$, $\eta_p^2 = .07$. Further analyses showed that children's performance improved significantly over time in both groups; ASD: $t$ (45) = -8.62, $p < .001$; controls: $t$ (37) = -5.11, $p < .001$. Figure 4.3 shows that both groups demonstrated an improved performance on mental state/emotion recognition after 12 months, but the ASD group showed a steeper developmental change (source of interaction). The ASD group's poorer performance insisted throughout this developmental period.

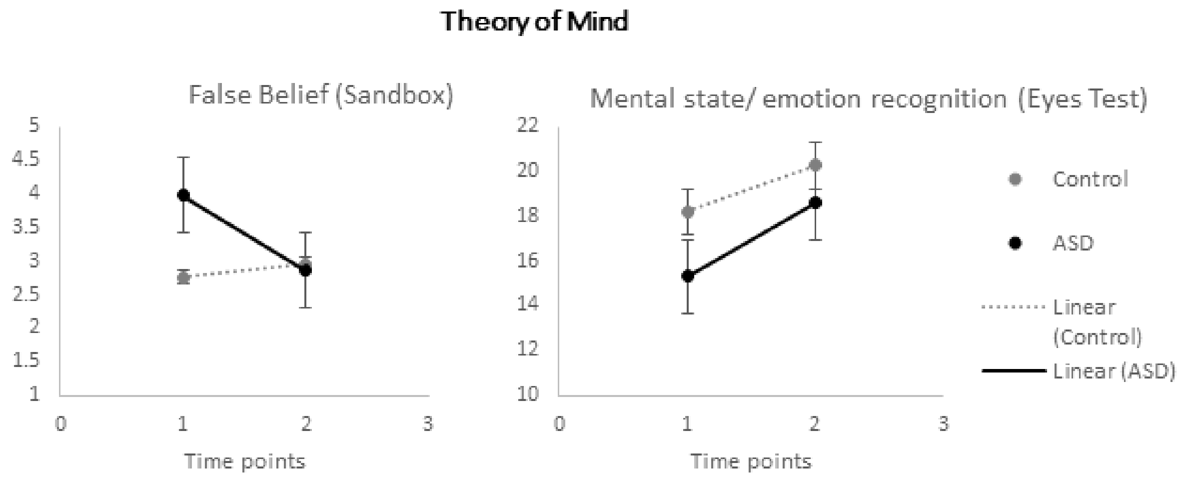


**Figure 4.3. Mean ToM scores across 12 months for ASD and control groups.**

### 4.3.2. Longitudinal relations between EF and ToM in children with and without ASD

Pearson's correlations were conducted to investigate the relation between hot & cool EF and ToM across the two time points (see table 4.3) in children with and without ASD. Table 4.3 shows that cool EF (digit span, ToL, Go-No Go scores) and both ToM tasks were significantly correlated at both time points. In terms of hot EF, only delay discounting was significantly related to ToM Eyes Test whereas performance on IOWA (affective decision making) was not significantly related to ToM at any of the time points.

Table 4.3. Correlations between ToM and EF tasks across the two time points.

| | False Belief T1 | False Belief T2 | Eyes test T1 | Eyes Test T2 |
|---|---|---|---|---|
| T1 Inhibition | .09 | -.05 | -.37** | -.18 |
| T1 Planning | -.27* | -.14 | .21* | .19 |
| T1 WM | -.14 | .10 | .24* | .04 |
| T1 IOWA | .014 | -.04 | .18 | .10 |
| T1 Delay | -.12 | -.03 | .25* | .24* |
| T2 Inhibition | .14 | -.04 | -.38** | -.21 |
| T2 Planning | -.35** | -.16 | .31** | .24* |
| T2 WM | -.16 | -.18 | .18 | .09 |
| T2 IOWA | -.13 | -.11 | .11 | .004 |
| T2 Delay | - .12 | -.02 | .12 | .15 |

Note. *p < .05, **p < .01.

Following the correlational analysis, the predictive association between EF and ToM in children with and without ASD was examined by running two series of hierarchical regression models. The first series of regressions investigated whether early EF predicted later ToM (at T2). Block 1 of predictors included ASD diagnosis, concurrent age, concurrent Full Scale Intelligence Quotient (FSIQ) and early ToM (control variables). Block 2 of predictors introduced the individual cool EF skills in order to examine the predictive role of EF on ToM over and above control variables. Block 3 included the hot EF (only delay discounting; IOWA scores were not included in the regression models as they did not correlate with any ToM task at either time point) in order to assess whether hot EF can predict ToM over and above control variables and cool EF. Finally Block 4 of predictors included the hot delay discounting X ASD diagnosis interaction term, computed from the cross-product of effect-coded ASD (-1=Autistic,

+1=Control) and the centred hot delay discounting scores (Aiken & West, 1991), in order to examine whether the association of hot EF to ToM was stronger in either controls or ASD. The second series of regressions investigated whether early ToM predicts later EF (at T2), after controlling for concurrent age and FSIQ, and early EF.

**EF predicting later ToM mental state/ emotion recognition (EyesTest at T2):**

The first block of predictors (ASD diagnosis, concurrent age & FSIQ, and early Eyes Test scores (T1) contributed significantly to the variance of the later Eyes Test scores, $F$ (4, 77) = 22.11, $p$ < .001, explaining 53.5% of the variance. Neither for cool EF entered in block 2 [$F$ (5, 72) = 0.97, $p$ =.44] nor hot EF in block 3 [$F$ (2, 70) = .66, $p$ = .52], significant additional variance was explained. Finally for the Hot delay discounting X ASD interaction terms entered in block 4, the total variance explained rose to 66.2% [$F$ (2, 68) = 9.07, $p$ < .001]. Later ToM Eyes Test scores (T2) were significantly predicted by the early (T1) ($p$ = .002) and later (T2) ($p$ = .002) hot delay discounting X ASD diagnosis interactions terms. Thus, early and later delay discounting predicted later ToM mental state/ emotion recognition only in school-aged children with ASD.

**EF predicting later ToM false belief (Sandbox scores at T2)**

The first block of predictors (ASD diagnosis, concurrent age & FSIQ, and early false belief scores (T1) contributed significantly to the variance of the ToM false belief ability, $F$ (4, 77) = 6.52, $p$ < .001, explaining 25.3% of the variance. For cool EF entered in block 2 the total variance explained rose to 39.8%, representing a significant increase of 14.5% [$F$ (5, 72) = 3.48, $p$ =.007] additional variance explained. Neither for hot EF entered in block 3 [$F$ (2, 70) = 0.31, $p$ =.74] nor for the hot delay discounting X ASD interaction entered in block 4, [$F$ (2, 68) = 2.07, $p$ =.13] significant additional variance was explained. Later ToM false belief scores (T2) were significantly predicted by early working memory (Digit span T1) ($p$ = .0004) and later working memory (Digit span T2) ($p$ = .0002) overall in school-aged children with and without ASD.

### Early ToM predicting later hot and cool EF skills

None of the regression models with early ToM skills predicting each one of the individual later hot and cool EF skills were significant. Early ToM skills did not predict later EF in school-aged children with and without ASD (see table 4.4).

Table 4.4. Regression analysis for each cool and hot EF task by group and ToM variables.

| Predictors | Digit Span(T2) | | ToL(T2) | | Go/No-Go(T2) | | Delay(T2) | |
|---|---|---|---|---|---|---|---|---|
| | β | $\Delta R^2$ | β | $\Delta R^2$ | β | $\Delta R^2$ | β | $\Delta R^2$ |
| Block 1 (Control variables) | | .62** | | .35** | | .95** | | .13* |
| Concurrent Age | .12 | | .04 | | .005 | | -.15 | |
| ASD diagnosis | -.06 | | .17 | | -.09 | | .01 | |
| Concurrent IQ | .19* | | .05 | | .02 | | -.05 | |
| (each) Early EF | .74 | | .53** | | .94** | | .34* | |
| Block 2 (ToM skills) | | .07 | | .04 | | .001 | | .005 |
| Early False Belief | .08 | | -.16 | | .03 | | .08 | |
| Later False Belief | -.29 | | -.02 | | -.01 | | -.03 | |
| Early Eyes Test | -.09 | | .12 | | .03 | | .04 | |
| Later Eyes Test | .02 | | -.01 | | -.04 | | -.06 | |
| $R^2$ | | .69 | | .39 | | .95 | | .14 |
| F test | | 4.33 | | 1.14 | | .35 | | .11 |

Note. *p<.05, **p<.01.

## 4.4. Discussion

The present study examined the developmental changes of cool and hot EF and their associations to ToM over a one year interval in school-aged children with and without ASD. This longitudinal analysis demonstrated that for children with ASD, selective aspects of EF (working memory, inhibition, and affective decision making) presented significant age-related gains after one year but their impairments, present from the initial assessment (i.e. Study One), remained throughout development without reaching the levels of neurotypicals. For "cool" planning, ASD participants showed equal performance and the same developmental gains relative to controls while for "hot" delay discounting there were no deficits or developmental changes found in ASD or typical development. With regards to ToM abilities, the mental state/ emotion recognition presented age-related improvements but demonstrated a pattern deviant to controls as children's deficits from initial assessment (Study One) remained present across time in ASD. For false belief, results suggested it followed a delayed developmental pathway in ASD as deficits disappeared with age. Second, results of the longitudinal association between cool and hot EF and ToM in school-aged children with and without ASD revealed that selective early aspects of EF (working memory, and delay discounting) predicted later ToM abilities which partially supports the well documented theoretical account of early EF predicting later ToM. No evidence was found to support the argument that ToM abilities predict later EF. Cool EF working memory predicted later ToM false belief overall in children with and without ASD, while hot delay discounting predicted later ToM mental state/ emotion recognition over and above cool EF and control variables only in the ASD participants. Expanding findings of Study One that presented significant associations between both hot and cool EF and ToM, Study Two reported for the first time that there is in fact a strong functional link between these abilities across middle childhood. The fact that early hot delay discounting predicted later ToM above and beyond cool EF in school age in the ASD group highlights the multidimensional nature of EF and how (similar to Study One) its influence on other developmental landmarks such as ToM may increase understanding of the higher-order cognitive deficits that underpin social interaction problems in ASD.

### 4.4.1. Development of EF and ToM across time in school age

The present results demonstrated that children with ASD showed age-related improvements in all cool EF aspects suggesting that during school age (middle childhood) specific aspects of EF (working memory, inhibition, planning) present developmental gains in ASD. These results support previous evidence of performance gains in EF during childhood both in typical development (Carlson et al., 2013; Gur et al., 2012) and in ASD (Pellicano, 2010). These findings contradict two of the three previous longitudinal EF studies in ASD that reported no developmental improvements in EF, either in young children (Griffith et al., 1999) or adolescents (Ozonoff & McEvoy, 1994). Both of these studies indicated very few EF changes across time and suggested that probably there is a ceiling on the development of such cognitive abilities in ASD. In line with the third longitudinal EF study though (Pellicano, 2010), these findings paint a more positive picture of autistic children's EF developmental trends, indicating perhaps the likelihood of a window of plasticity in ASD as well. Notably, the contradicting studies (Griffith et al., 1999; Ozonoff & McEvoy, 1994) included ASD participants much less able than in the present study which may account for their lack of significant developmental changes. However, it should be noted that despite the reported developmental changes in cool working memory and inhibition, children with ASD presented impairments in these aspects relative to matched neurotypicals which remained present across development, never reaching the performance level of the control group. This evidence provides some support for Happé et al. (2006b) proposition that there may be a particular profile of "coexisting cognitive atypicalities" in ASD that pertain across development. One could argue that this could suggest that children with ASD might eventually reach a performance ceiling in some EF aspects as Ozonoff and McEvoy (1994) implied in their study. The present data failed to provide more evidence relating to this issue as the present longitudinal design included only two time points and the sample did not include adolescents or young adults which could shed more light on the maturity peaks of EF in ASD (if they ever develop up to the same level as controls). The present data indicate thus that despite the significant age-related improvements in working memory and inhibition, the performance of the ASD group never reached that of controls which implies *deviant* development across the age range of the present sample. The suggested deviant development should not allow though for the present data to be overlooked. More specifically, it is worth considering the present data from the maturation processes perspective of Luna et al. (2007) who proposed that if deficits in EF persist across development, it could imply that impairments in the underlying EF brain mechanisms are not related to the brain developmental/ maturation processes. This, in conjunction with the emerging developmental improvements found here, could suggest that the developmental processes may be intact for ASD participants across this specific age range (middle childhood). The fact that planning ability presented an intact profile and similar developmental improvements to the control group (no deviance) as also shown in a previous study (Happé et al., 2006a) could actually add more support to this notion that, at least in school age, developmental/ maturation processes of selective cool EF are intact in ASD. The developmental pattern of cool EF gains in school age could be explained in relation to the prefrontal cortex (the underlying brain region of EF) undergoing substantial maturation during this period (Otero & Barker, 2014). School age is a crucial period of rapid developmental improvements and increased cognitive demands where children have to process and understand both their own sense of self and their sense of others as well as learning to interact effectively with the world around them (Siegel, 2013) which could justify these advances.

School age is an important developmental period demanding not only cool EF improvements, but also hot EF gains, as the social contexts children are faced with involve advanced emotional and motivational processes. This is the first study to examine the developmental changes of hot EF in ASD across time and showed that only affective decision making presented significant age-related gains in school-aged children with ASD. These results are in line with previous research (Hooper et al., 2004; Prencipe et al., 2011) that reported age-related performance gains in the Iowa Gambling Task across childhood and adolescence as well as with developmental theories proposing that the development of hot EF would be protracted to the extended development of the underlying brain region that is the ventromedial prefrontal cortex, across school age (Segalowitz & Davies, 2004). As with the cool EF developmental framework discussed above, despite the emerging developmental improvements, children with ASD presented deficits in the Iowa Gambling Task relative to the control group that did not become less marked with age (*deviant* to control group development across middle childhood). The emerging developmental gains in this hot EF aspect, despite the persisting deficits, highlight the importance of this finding since it suggests that the developmental/maturation processes of the brain structures underpinning selective hot systems in ASD continue across school age. The cognitive maturation processes of the areas of ventromedial prefrontal cortex regulating affective decision making seem to progress across school age in ASD.

Contrary to the significant results of cool EF and hot affective decision making, hot delay discounting demonstrated non-significant developmental changes neither in ASD nor typical development. These results contradict previous cross-sectional evidence having indicated age-related improvements in the delay discounting task (Scheres et al., 2006) across childhood and adolescence. Scheres et al. (2006) employed a temporal and probabilistic discounting task that had a differentiated design with shorter time delays, smaller immediate monetary rewards as well as levels of probability for the delayed reward. Besides this, the monetary awards they offered were real, contrary to the ones in the present study being hypothetical due to the impractical cost and ethical issues raised within the school contexts. Such discrepancies in the measures used could have perhaps made their older participants more motivated to wait for the larger rewards during the task relative to the younger ones resulting in the reported age-related gains. As the differentiated designs of delay discounting tasks are multifaceted and with levels of difficulty/complexity, it could be suggested that the present delay discounting task's dimensions were not developmentally sensitive enough to capture subtle age-related differences across school age in either group. Steinberg et al. (2009) in fact suggest that differentiated task designs do not likely follow the same developmental pathway. Besides task discrepancies though, the lack of significant developmental changes in hot delay discounting relative to the other hot aspect (affective decision making) is quite surprising and raises questions about their underlying brain structures and developmental course. One should expect the delay discounting trajectory to progress across school age as children are in greater need of their impulsivity control (tapped by delay discounting) within the more demanding social and educational settings. As findings from early childhood (Zelazo, & Carlson, 2012) and adolescence (Scheres et al., 2014) have both demonstrated age-related gains, it makes us consider the possibility that delay discounting may present a developmental pause during middle childhood (7-12) years before continuing to progression in adolescence. This assumption needs to be cautiously interpreted as the present design did not include a third time point across school age but will be further explored in the next study that assessed the developmental trends of hot EF from childhood to adolescence in ASD and typical development.

Regarding the developmental course of ToM in ASD, discussion will not go in great depth as the main focus in the present study was its longitudinal association to EF across school age. ToM mental state/ emotion understanding ability and false belief understanding ability both made substantial progress in ASD across the 1-year period and expand relevant findings from longitudinal studies in preschool period (Pellicano, 2010; Steele et al., 2003) to middle childhood as well. The ASD performance in the mental state/ emotion recognition task never reached the level of the control group despite the age-related gains. This suggests that, as with cool EF described above, the developmental trend of this ToM ability was *deviant* of the typical development one. The small but significant changes however highlight that ToM gains, should they occur, may be present beyond preschool period in ASD. In contrast to this, the false belief task in ASD presented a differentiated developmental course as impairments were present only at the initial assessment point. Age-related gains emerged only in the ASD group, with false belief performance reaching the controls' level at the second time point. This could imply that false belief ability in ASD presents a *delayed* developmental pattern in our study. Failure to report developmental gains in the control group is due to ceiling effect (Sandbox task probably not sensitive enough to developmental trends of typical development). It seems that the ASD heterogeneity and the unique ToM profiles of distinct tasks cannot allow for either the delayed or deviant development hypothesis to fully explain the ToM deficits in ASD. These data support Baron-Cohen's (1991) proposition that ToM development in ASD fits a hypothesis of both deviance and delay. The development of ToM will be investigated further (up to adolescence) in the next chapter.

### 4.4.2. Longitudinal associations between hot and cool EF and ToM across time in school age

The present results showed that EF and ToM are developmentally linked across school age. In line with the vast majority of previous studies (for a review see Devine & Hughes, 2014), early EF predicted later ToM rather than the reverse pattern (early ToM predicting later EF). Therefore these findings add more to the theoretical account suggesting that emerging EF in childhood is a potent, although not exclusive, platform for the development of ToM both in typical development (Flynn, 2007; Hughes, 1998b) and ASD (Pellicano, 2010). The emergence account of ToM posits that early EF skills predict later ToM; thus children would first need to obtain sufficient EF skills and then understand and process ToM false beliefs or mental states **(**Russell, 1996**).** Indeed, after controlling for concurrent age, FSIQ, and prior ToM, it was found that early working memory predicted later ToM false belief overall, while early delay discounting predicted later ToM mental state/emotion recognition in ASD. These findings thus do not support Perner's (1998) proposition that the acquisition of ToM is a prerequisite of children's EF, according to which, longitudinal predictions from earlier EF are not expected for a ToM task.

In line with the proposed hypothesis and previous cross-sectional and longitudinal studies that presented associations between cool EF and ToM in typical development and ASD (Carlson & Moses, 2001; Pellicano, 2007; Kimhi et al., 2014), it was found that later ToM false belief was predicted by early cool working memory. Children between 3 and 5 years of age present dramatic and rapid improvements in EF and ToM (Anderson, 2008) but the present findings suggest that developmental changes in ToM mechanisms across middle childhood (beyond 5 years) may require EF to facilitate the emergence of more sophisticated ToM abilities. Advanced needs for cognitive executive control during school age are required as, within this context, children have to maintain and manipulate new, complex knowledge while socially interacting with their environments (Del Giudice, 2014). This evidence supports the working memory hypothesis according to which the working memory development is an important factor influencing children's developing understanding of false belief (Davis & Pratt, 1995) in early childhood, as replicated by other studies too (Gordon & Olson, 1998; Keenan et al., 1998). It could also be argued that across school age (middle childhood) children with or without ASD need an improved working memory ability that can enable them to successfully develop ToM mechanisms. Working memory and inhibition are generally considered central to the EF-false belief relation (Carlson et al., 2002; Devine & Hughes, 2014), a notion for which limited support was provided. Contradicting prior studies in early childhood (Carlson et al., 2013; Carlson et al., 2004), inhibition did not predict early or later ToM false belief in school age in the present study. One could thus argue that inhibition may be more central to the emergence of false belief in the early years of childhood (Tillman et al., 2015) and as ToM abilities progress across childhood, other EF may be more central to the development of ToM.

Another important finding of the present study was the significant longitudinal predictive association found between hot delay discounting and ToM mental state/ emotion recognition, over and above cool EF and control variables in ASD. Current findings corroborate to an extent that there may be a developmental relation of the underlying brain mechanisms of selective hot processes and ToM present in ASD across time. Delay discounting could be linked with the emergence of ToM as, in order for children with ASD to understand the mental states of others, “hot” motivational or emotional processes need to be evoked (Zelazo et al., 2005) across school age. This emerging link built on the cross-sectional association found in Study One and suggests that the ability of school-aged children with ASD to disengage from the present while considering more long-term goals/ temporal perspectives (delay discounting) may provide a platform for the development of one’s emotion understanding ability. Thus the present findings answer the question raised from results in Study One regarding the directionality of the delay discounting- ToM relation. It seems that hot delay discounting provides a platform for the development of emotion recognition ability and not vice versa.

Stolarski (2011) has indeed suggested that emotional functioning is linked with the development of temporal perspectives (i.e. delay discounting). As this longitudinal association between delay discounting and mental state/ emotion recognition was found only in the ASD group, it could imply there is a specificity in the relation between ToM and this hot executive process in ASD. However as delay discounting did not predict later false belief (the other ToM task) this assumption has to be examined cautiously. The developmental association between these delay related motivational processes and ToM mechanisms being stronger in the ASD group needs to be tackled by future imaging studies investigating the structure of the underlying brain regions. For example, previous fMRI research in clinical population showed an association between ADHD and activity in the ventral striatum (brain region responsible for preference for small more immediate rewards over large delayed rewards; McClure et al., 2004) during reward anticipation in delay tasks (Scheres et al., 2007; Strohle et al., 2007). Relevant research could perhaps clarify if that could also the case for ASD.

The present findings need to be interpreted cautiously and also be corroborated with results from larger longitudinal studies with more than two time points across school age. Clear conclusion about the longitudinal association between hot EF and the broader ToM mechanism cannot be drawn as early hot delay discounting predicted only one of the two later ToM measures addressed here. Moreover, these two ToM measures tap only some of the various ToM skills and cannot be considered as the only crucial ToM measures. Future longitudinal research thus could investigate the impact of hot EF to several other ToM tasks.

In conclusion, the present study demonstrated that for children with ASD, selective cool and hot EF skills, and ToM abilities presented significant developmental changes across time in middle childhood. These data highlight the need to shed more light on the underlying brain structures as the reported impairments in EF are likely not related to the maturation processes. Furthermore, these data provided more to the theoretical account that cool EF influences the development of ToM and not vice versa in ASD and typical development, while expanding these longitudinal associations of ToM to hot EF as well suggesting that specific hot EF skills (delay discounting) also provide a platform for the emergence of ToM across middle childhood in ASD. Finally, findings of specific EF predicting later ToM contributed support to an emergence account (Russell, 1996) in typical development and ASD. Studying the developmental trends of hot and cool EF and their longitudinal associations to ToM may aid in gaining a greater understanding of the link between cognition and behaviour in typical development and of the development of higher-order cognitive impairments being a risk factor for poor developmental/ social outcomes in children with ASD. It should be noted at this point that the assumptions described throughout discussion that the persisting performance deficits of selective EF in the ASD group (despite the developmental improvements found) suggest a deviant rather than a delayed pattern apply only to the specific age range (middle childhood) employed in Study Two. As this data could not reveal how such impairments evolve with age (e.g. if they ever reach a maturity peak), the following study (Study Three), has employed a larger sample size of children and adolescents too and aimed to examine whether these group differences may eventually lessen with further age (during the transition from middle childhood to adolescence). Furthermore, Study Three aimed to examine whether age-related changes in EF would still predict ToM in children with and without ASD across a broader developmental period (7-16 years). Although Study Two showed that middle childhood is still a sensitive period for the development of EF, it should be borne in mind that prefrontal brain areas experience a substantial re-organisation during the transition to adolescence as well, when the volume of gray matter in prefrontal cortex reaches a peak (Giedd et al., 1999). This re-organisation of the adolescent brain has been found associated with increases in the rate at which EF develops (Zelazo & Carlson, 2012) and highlights the need to expand investigation of EF development beyond childhood.

## Chapter V

## Study 3. HOT AND COOL EXECUTIVE FUNCTION AND THEORY OF MIND IN CHILDREN AND ADOLESCENTS WITH AUTISM SPECTRUM DISORDER: CROSS-SECTIONAL DEVELOPMENTAL TRAJECTORIES

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### Abstract

As already discussed in Study Two, the development of EF in ASD has been investigated mainly using tasks tapping only the "cool"-cognitive- aspects of EF. Expanding findings of Study Two, the present study aimed to identify the developmental trajectories of "hot"-affective- EF processes beyond middle childhood as relevant knowledge in ASD is minimal. Study Three especially focused on whether cool and hot EF follow a similar developmental pathway in ASD, relative to controls, during the transition to adolescence. Finally, considering that previous investigations of the EF-ToM relationship in adolescence in ASD and typical development employed only cool EF tasks, the present study built on Studies One and Two, by exploring whether the strong developmental associations of hot EF and ToM found in middle childhood is still significant in adolescents with and without ASD. This study employed a cross-sectional developmental trajectories approach to examine the age-related changes in both cool *(working memory, inhibition, planning)* and hot (*affective decision making, delay discounting*) EF as well as ToM of ASD participants (n=79) and controls (n=91) relative to age and IQ, shedding more light on the hot-cool EF organisation. The interrelation between the developmental trajectories of cool & hot EF and ToM was also explored. Results demonstrated that the developmental trajectories of some cool EF (working memory, planning) differed significantly as a function of age in ASD participants relative to controls. For hot EF, no significant age-related improvements were found. Gains were reported in both ToM measures in ASD. Developmental trajectories of cool and hot EF skills were related to the ToM developmental trajectory beyond middle childhood, in ASD and typical development.

**Chapter Overview.** The present study follows a cross-sectional developmental trajectories approach and built on the first two studies by expanding the age range of developmental investigations in adolescence (beyond school age/ middle childhood). Expanding the investigation of the developmental pathway of EF in adolescence as well is quite important as the adolescent brain continues to experience developmental plasticity (Zelazo & Carlson, 2012) and may reveal important information about maturity peaks of EF in ASD relative to controls. Moreover, building on the results from the first two studies, Study Three aimed to explore whether group differences in EF skills would disappear with age in adolescence. This study investigated the cross-sectional developmental trajectories of cool and hot EF as well as their relation to ToM in children and adolescents with and without ASD, aged 7-16 years old. Examining the developmental patterns of EF and ToM beyond middle childhood, up to adolescence, may aid in identifying whether ToM and EF still share joint developmental patterns. Finally, given that results so far have shown that hot and cool EF give rise to different developmental outcomes and also follow differentiated developmental pathways in ASD and typical development across middle childhood (Study Two), there are reason to suspect that the internal organisation of cool and hot EF skills would be different in each group. Study Three addressed these concerns. This chapter adopts a more neuropsychological approach of the topic, linking cognitive behaviours (i.e. EF) with neural mechanisms, in an attempt to provide some preliminary evidence about the underlying brain maturation processes taking place in ASD across development. Such data may provide a solid ground for future imaging or electrophysiological studies.

## 5.1. Introduction

Research on the development of EF has indicated that the emergence of EF occurs in the early years of life, followed by critical changes throughout the preschool era (Moriguchi, 2014). The maturation of the EF occurs in adolescence, protracted to the development of the prefrontal cortex (Anderson, 1998). In typical development the developmental pattern of cool EF inhibition is suggested to show rapid improvements between 3 and 5 years of age, followed by less dramatic advances between 5 and 8 years and even slower increases in adolescence. Several, possibly overlapping areas of the prefrontal cortex, including the dorsal areas of the lateral prefrontal cortex and the anterior cingulate cortex and inferior frontal gyrus are suggested to interact in order to facilitate inhibition task performance (Duncan & Owen, 2000; Konishi, Jimura, Asari, & Miyashita, 2003). Despite age-related improvements in task performance often being subtle across middle childhood and adolescence, the underlying neural activity changes more dramatically (Johnstone et al., 2007), with greater brain localisation and efficient activation in the aforementioned brain regions, pertinent to task completion (Best & Miller, 2010). The developmental trajectory of working memory ability is suggested to present linear increases from preschool age to adolescence (14 years). Neuroimaging evidence has shown that the neural basis underpinning working memory is the dorsolateral prefrontal cortex (Best & Miller, 2010; Funahashi, 2004), with the left temporo-frontal cortex specifically found to be implicated in verbal working memory tasks (Thomason et al., 2009). The protracted neural developmental trajectory of working memory involves regressive and progressive alterations and leads to localised activity within the prefrontal cortex network of connectivity (Best & Miller, 2010). Finally, in terms of planning, evidence has demonstrated poor performance in young childhood with age-related improvements across middle childhood and adolescence (11-14 years) (de Luca et al., 2003). Evidence from imaging studies suggests that the activated brain areas during planning tasks are localised in the circumscribed neural assemblies of the mid-dorsolateral part of the prefrontal cortex (Bechara et al., 2000; Manes et al., 2002; Unterrainer & Owen, 2006). Relative to cool EF tasks that mainly rely on the dorsal and lateral prefrontal cortex, as described above, evidence from lesion studies and Krain et al.'s (2006) meta-analysis has shown that particular hot EF aspects (i.e. affective decision-making) may be underpinned by different areas such as the orbitofrontal and ventromedial regions of the prefrontal cortex (Bechara, 2004). Limited evidence to date has shown that hot and cool trajectories are weakly related during transition to adolescence, with hot EF possibly following a differentiated independent developmental trajectory after middle childhood (Hooper et al., 2004; Prencipe et al., 2011).

It is unclear whether the developmental trajectory of cool and hot EF in ASD is similar to that identified in typical development, prompting questions about the nature of the executive dysfunction in ASD. The few developmental studies investigating EF chronological age-related changes from childhood to adolescence in ASD have used traditional matched-group comparisons that do not allow for drawing conclusions regarding the continuous change of EF over the course of development. Furthermore, they focused only on cool aspects yielding inconsistent results; some report age-related gains (Happé et al., 2006a; Van Eylen et al., 2015) an others non-significant developmental changes (Luna et al., 2007; Ozonoff et al., 2004). Evidence from previous neuroimaging studies in ASD in several brain areas, including the frontal cortex, have documented atypical patterns of white and grey matter volumes (Carper &

Courchesne, 2005; Mak-Fan et al., 2012), functional connectivity (Just et al., 2004; Koshino et al., 2005) and brain lateralisation (McPartland et al., 2004) relative to typical development. Despite the substantial evidence for abnormalities in the development of the frontal lobes within the autism spectrum, the associations of these circuits with cognitive performance/ behavioural phenomena are not clear (Griebling et al., 2010). It remains to be investigated whether EF impairments in ASD arise from prefrontal cortex deficits (i.e. deficient connectivity) or other underlying system impairment such as maturation (i.e. myelination changes) across development. Although the present study did not include neuroimaging or electrophysiological data, it is strongly believed that developmental studies with broad age ranges could provide a solid ground to clarify, theoretically first, whether there is a developmental delay or deviance across development or whether group differences lessen with age (e.g. developmental deficits from Study Two) between controls and individuals with ASD.

No study to date has investigated the development of hot EF from childhood to adolescence ASD. As already discussed, investigating developmental trends of EF in ASD is important to provide a better insight into the brain maturation mechanisms in ASD and may shed light on potential implications for treatment. Moreover, there is no study to date having explored whether cool and hot EF subcomponents are distinct in ASD. Making speculations about the distinction of hot and cool EF in ASD is hard as there is no empirical evidence. For example, brain activation/ localisation during distinct EF tasks has not been examined in ASD (Hill & Frith 2003). Potential differences in the developmental trajectories of hot and cool EF within broad age ranges is a “hot”, open topic of debate that the present study aims to address. Such data would be crucial to identify the organisation and developmental relationship of cool and hot EF skills that could aid in overcoming the limitations of current theories of EF development and lead to a better understanding of the heterogeneity in neurocognitive impairments in ASD.

**EF-ToM association in adolescence**

Study Two showed that, in line with previous evidence (Carlson, Claxton, & Moses, 2013; Pellicano, 2010), improvements in EF across development have been found to be intimately tied to the development of ToM in ASD and typical development. Study Two further expanded this association by presenting a functional link between hot EF and ToM for the first time in ASD. However, less is known about the extension of this relation in adolescence. A further question that needs to be addressed in Study Three lies on whether the associations between the developmental trajectories of both cool and hot EF to ToM are still associated in adolescence as in middle childhood (shown by Studies One and Two) in ASD.

**Current Objectives**

The main goal of this study was to investigate whether the developmental trajectories of hot and cool EF differ relative to chronological age and IQ between children and adolescents with ASD and controls. IQ was included in analysis as previous studies have revealed a significant relation between cool EF and IQ in ASD participants, suggesting that higher IQ scores are associated with better performance in cool EF abilities on a variety of different measures (Arffa, 2007; Pellicano, 2007, Van Eylen et al., 2015). Taken together, the developmental studies described in Chapter One, show there is no clear developmental framework of EF in ASD due to inconsistent results; with some reporting age-related improvements in EF and others not. In addition, there may be different developmental patterns for different aspects of EF (i.e. cool and hot). Moreover, to date no research has investigated the development of hot EF across a broad age range in ASD. Employing tasks to assess both cool and hot EF skills, the current study will shed more light on the developmental pathway of EF followed in ASD from childhood to adolescence. Instead of the traditional group comparison, a cross-sectional developmental trajectories approach was employed that uses cross-sectional data to explore developmental relationships by focusing on changes in domains of interest. Contrary to testing differences in cross-sectional group means, which masks changes associated with age or other foundational cognitive abilities, the trajectories approach evaluates group differences with respect to two coefficients, the intercepts and slopes of development. This methodology could reveal important information about the nature of development as it identifies not only early onset but also slower or deviant rates of development across neurodevelopmental disorders (Thurman et al., 2015). The developmental trajectories approach has also been found efficient in identifying several aspects of behavioural phenotypes (Kover et al., 2013). However, to date no research has used this as a method of understanding whether the development of EF, fractionated into hot and cool subcomponents, relative to crucial confounding variables such as chronological age and IQ, is similar to development within typically developing groups. This may shed more light on the similarities and differences between hot and cool EF developmental pathways followed in ASD relative to neurotypical controls.

A secondary aim was to investigate the association and internal organisation of hot and cool EF in ASD. Based on evidence from typical development (Hooper et al., 2004; Prencipe et al., 2011), it was hypothesised that cool and hot EF skills would be (even weakly) associated in the control group. It was sought to determine whether the ASD group would present a similar pattern.

The final aim of the present study was to explore the developmental relation between cool and hot EF and ToM in ASD from childhood to adolescence. It is suggested that hot EF may be particularly important to ToM (Zelazo et al., 2005), as corroborated by Studies One and Two as well, and it was thus hypothesised that both cool and hot EF developmental trajectories would predict ToM across childhood and adolescence.

## 5.2. Methods

### 5.2.1. Participants

This study used the same cohort of participants of Studies One and Two, but with an additional number of older participants (adolescents) for the purposes of drawing developmental trajectories across a broad age range. Seventy nine children and adolescents (79) with an official diagnosis of ASD (M=11.27 years, SD=2.56) and ninety one (91) controls (M=10.80 years, SD=2.49) aged 7-16 years old were recruited to participate in the present study. Participants were matched for chronological age ($t\ (170) = -1.21$, $p = .23$) and IQ ($t\ (170) = 1.79$, $p = .8$). Table 5.1 shows descriptive characteristics (means and standard deviations) of participants of both groups.

### 5.2.2. Measures

A detailed description of the measures is given in the methodology chapter (Chapter 2).The same measures of hot and cool EF and ToM presented in Chapter Three (Study One) were used in the present study as well. Cool EF were assessed by measures tapping inhibition, planning and working memory abilities, while hot EFs were assessed by tasks of affective decision making and delay discounting abilities. ToM was assessed using a false belief task

(Sandbox task) and one of mental state/ emotion recognition task (Reading the Mind in the Eyes test).

### 5.2.3. Statistical analysis

Preliminary analysis: Pearson's correlations were run between all EF measures, chronological age and FSIQ. Main Analysis: Developmental cross-sectional trajectories were assessed employing the methods outlined by Thomas et al. (2009) for both hot and cool EF measures, relative to chronological age and FSIQ. More specifically, in order to compare linear regressions, the Analysis of Covariance function within the General Linear Model (ANCOVA) is adapted (chronological age or IQ is used as a covariate). This methodology is thought to be equivalent to introducing dummy variables in linear regression models, when one is interested in assessing the significance of dichotomous or categorical variables and their interaction with continuous variables (Suits, 1957). This method requires the specification of three appropriate effects within the model: main effect of Group, main effect of the covariate (Age), and the interaction between Group and the covariate (Group x Age). When those are computed, the differences between the slope and intercept of the lines depicting the developmental trajectory of each group are evaluated, instead of comparing the cross-sectional group means. In the present study, the main effect of group (ASD or control), main effects of predictors (chronological age, FSIQ) and the interactions between group and slope were investigated.

## 5.3. Results

### 5.3.1. Preliminary analysis

Before turning to the trajectory analyses, the average group differences in each EF task were assessed. Significant group differences were found between the two groups performances both on cool EF: Go/No-Go ($F$ (1, 163) = 23.08, $p$ < .001, $\eta^2$= .13), Digit Span ($F$ (1, 169) = 28.21, $p$ < .001, $\eta^2$= .14), ToL ($F$ (1, 168) = 19.73, $p$ < .001, $\eta^2$= .11) and hot EF tasks: IGT ($F$ (1, 165) = 8.01, $p$ = .005, $\eta^2$= .05) and delay discounting ($F$ (1, 147) = 6.98, $p$ = .009, $\eta^2$= .05). The ASD group showed significantly poorer performance in each hot and cool EF task relative to the control group (see Table 5.1 for Means and SDs).

Results of the correlational analysis between hot and cool EF and developmental predictors (age and IQ) separately in both groups are included in table 5.2.

Table 5.1. Participants' characteristics.

| | Group | | |
|---|---|---|---|
| | ASD (*n*=79) | Control (*n*=91) | *F* values |
| **Age** (in years) | | | |
| *M (SD)* | 11.27 (2.56) | 10.80 (2.49) | |
| Range | 7-16 | 7-16 | |
| **FSIQ** | | | |
| *M (SD)* | 95.85 (15.09) | 99.78 (13.54) | |
| Range | 70-127 | 72-135 | |
| **Digit Span** | | | |
| *M (SD)* | 11.33 (3.09) | 13.97 (3.38) | 28.21 (p <.001) |
| **ToL** | | | |
| *M (SD)* | 7.05 (2.03) | 8.31 (1.65) | 19.73 (p <. 001) |
| **Go/No-Go** | | | |
| *M (SD)* | 48.86 (15.98) | 35.91 (18.11) | 23.08 (p< .001) |
| **IGT** | | | |
| *M (SD)* | -.04 (.19) | .05 (.22) | 8.01 (p = .005) |
| **Delay Discounting** | | | |
| *M (SD)* | .33 (.12) | .38 (.12) | 6.98 (p = .009) |

Note. ToL= Tower of London task; IGT= Iowa Gambling Task.

Table 5.2. Pearson's Correlation Coefficients among ToM and EF variables in both groups

| **ASD (n=79)** | FSIQ | Age | DigitSpan | ToL | Go/No-Go | IGT | Discounting | False B. | EyesTest |
|---|---|---|---|---|---|---|---|---|---|
| FSIQ | | -.51** | .34** | .37** | -.02 | .01 | -.07 | .01 | .32** |
| Age | | | -.25* | .04 | -.26* | .02 | -.1 | -.32** | .13* |
| DigitSpan | | | | .26* | -.11 | .28 | .07 | -.23* | .19 |
| ToL | | | | | -.01 | -.08 | .10 | -.32** | .46** |
| Go/No-Go | | | | | | -.02 | -.17 | .07 | -.32** |
| IGT | | | | | | | .03 | -.05 | .02 |
| Discounting | | | | | | | | -.09 | .37** |
| False belief | | | | | | | | | -.27* |
| **Control (n=91)** | FSIQ | Age | DigitSpan | ToL | Go/No-Go | IGT | Discounting | False B. | EyesTest |
| FSIQ | | -.45** | .09 | .04 | -.06 | .22 | -.14 | -.01 | .13 |
| Age | | | .57** | .45** | -.18* | .03 | -.15 | -.34** | .23* |
| DigitSpan | | | | .47** | -.23* | .26* | .14 | -.07 | .31** |
| ToL | | | | | -.07 | .18* | .12 | -.15 | .14 |
| Go/No-Go | | | | | | -.16 | -.24* | .27* | -.21* |
| IGT | | | | | | | .06 | .14* | .11* |
| Discounting | | | | | | | | -.03 | .00 |
| False belief | | | | | | | | | -.41** |

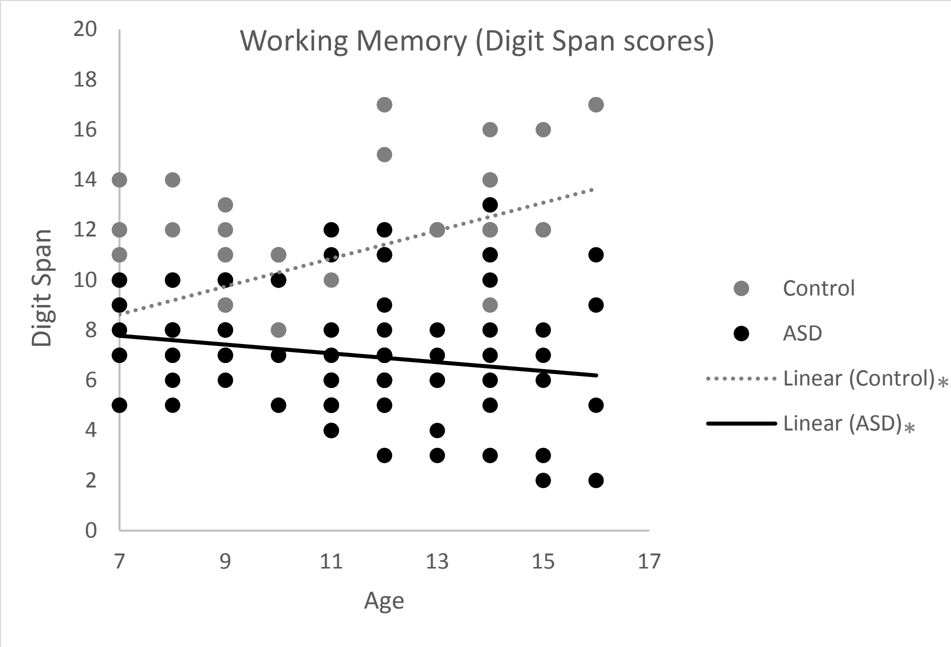
Note. *p <. 05, **p < .01; ToL: Tower of London, IGT: Iowa Gambling Task, EyesTest: Reading the Mind in the Eyes.

### 5.3.2. Main Analysis

#### 5.3.2.1. Cross-sectional developmental trajectories: cool EF

**Working memory** ability was assessed relative to chronological age using the digit span scores. The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age; 84 months) as well as the within-group trajectory slopes. The intercepts of digit span trajectory were not significantly different between the two groups $F$ (1, 169) = 1.84 $p$=.18, $\eta^2$=.011 suggesting that at the lowest age of overlap, performance was similar for both groups (*no delayed onset of development*). In terms of rate of change across age, chronological age was a significant predictor of the digit span scores $F$ (1, 169) = 5.01, $p$=.03, $\eta^2$ = .03. Moreover, it was crucially found that there was a significant Group X Chronological Age interaction, $F$ (1, 169) = 19.85, $p$< .001, $\eta^2$=.11. As indicated in table 5.3 and figure 5.1, for the control group, digit span scores improve with age while for the ASD group there was a significant trend for digit span sores to worsen with chronological age.

The developmental trajectory of digit span was also evaluated against IQ in terms both of intercept at the lowest point of overlap between the groups (Wechsler's scale score of 70- the lowest score reported) and within-group slopes. The intercept of the digit span trajectory differed significantly between the two groups $F$ (1, 169) = 4.63, $p$ = .03, partial $\eta^2$ = .03, indicating that at the lowest point for IQ there was an initial difference between the two groups on digital performance. IQ significantly predicted digit span scores $F$ (1,169) = 6.53, $p$ = .01, partial $\eta^2$ = .04; but this relationship was not statistically different between the two groups (no significant IQ x group interaction found) $F$ (1, 169) =.03, $p$ = .86, partial $\eta^2$ < .01. As seen in table 5.3 and figure 5.1, digit span scores improved when IQ scores were higher, for both groups.



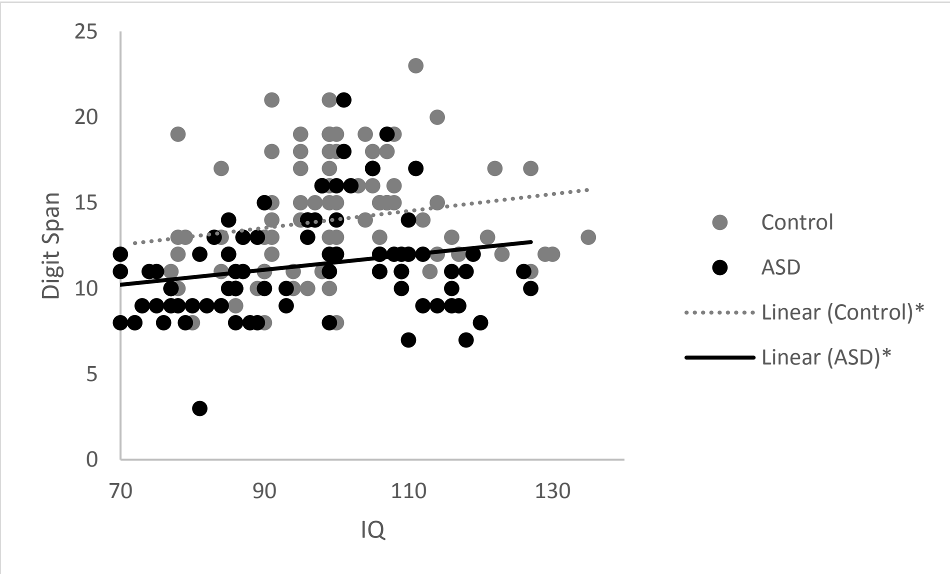




**Figure 5.1. Trajectory of verbal working memory ability relative to age and IQ for controls and ASD participants.**

**Planning ability** was assessed relative to chronological age using the ToL scores. The intercept of the trajectory was evaluated both at the lowest age of overlap between the two groups (i.e. 84 months) and within-group trajectory slopes. The intercepts of the two groups did not significantly differ, $F$ (1, 168) = .29, $p$=.594, partial $\eta^2$ =.002, suggesting that at the lowest overlap between the two groups (84 months) performance was similar for the two groups (no delayed onset). However, in terms of rate of change, chronological age significantly predicted the ToL scores $F$ (1, 168) = 8.46, $p$=.004, partial $\eta^2$= .05. A significant Group x

Chronological Age interaction was found as well $F$ (1, 168) = 5.83, $p$ = .017, partial $\eta^2$=.034. As seen in table 5.3 and figure 5.2, for the control group there was a significant developmental trend for ToL scores to improve with chronological age, but for the ASD group there was no significant age-related difference across children and adolescents.

The developmental trajectory of ToL scores was also evaluated against IQ in terms of intercept both at the lowest point of overlap between the groups (Wechsler's scale score of 70-the lowest score reported) and within-group slopes. The intercept of ToL trajectory differed significantly between the two groups $F$ (1, 168) = 11.46, $p$ = .001, partial $\eta^2$ = .07 at the lowest point of overlap between the two groups. IQ significantly predicted ToL scores, $F$ (1, 168) = 8.01, $p$ = .005, partial $\eta^2$ = .05, but the IQ x group interaction was not found significantly different, $F$ (1, 168) = 2.79, $p$ = .096, partial $\eta^2$ = .02. As seen in table 5.3 and figure 5.2, for both groups, ToL scores improved when IQ scores were higher.

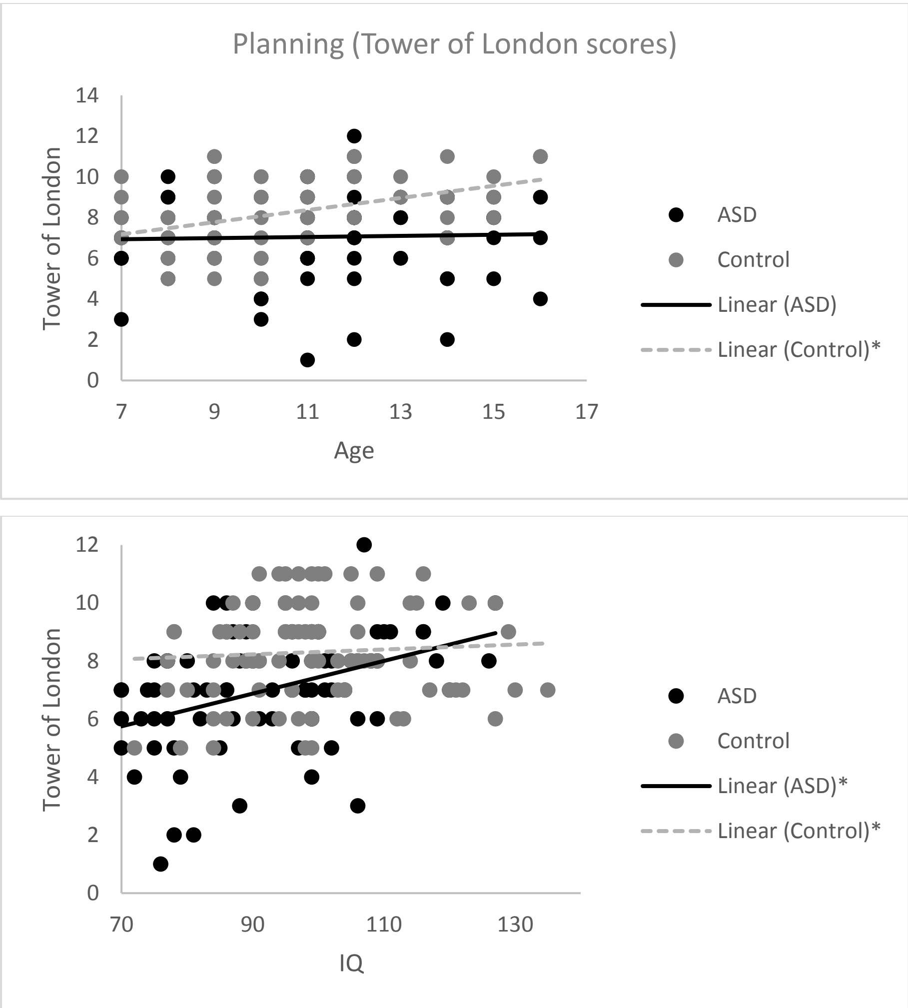
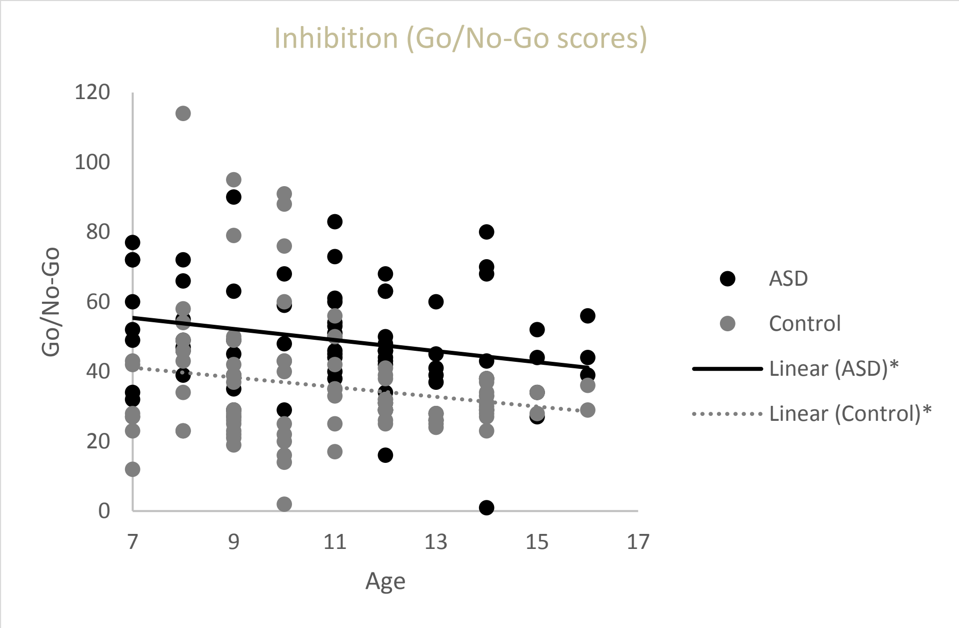



**Figure 5.2. Trajectory of planning ability relative to age and IQ for controls and ASD participants.**

**Inhibition** was assessed relative to chronological age using the go/no-go scores. The intercept of the trajectory was examined at the lowest age of overlap between the two groups (i.e. 84 months) as well as within-group trajectory slopes. Results showed that the intercept of the control group was significantly lower $F$ (1, 163) = 8.14, $p$ =.005, partial $\eta^2$=.048, indicating that performance of ASD participants was poorer at the lowest overlap between the two groups (delayed onset for the ASD group). For rate of change over development, chronological age was a significant predictor of the go/no-go scores $F$ (1, 163) = 7.36, $p$ =.007, partial $\eta^2$ =.044. The Group X Chronological Age interaction was not significant $F$ (1, 163) = .038, $p$ = .85, partial $\eta^2$ <.001. Figure 5.3 shows that for both groups, there was a trend for performance on Go/No-go measure to improve with chronological age.

The evaluation of the Go/No Go trajectory against IQ in terms of the intercept took place at the lowest point of overlap between the groups (Wechsler's scale score of 70-the lowest score reported) as well as within-group slopes. In terms of groups intercepts we found no significant differences $F$ (1, 163) = 2.65, $p$ =.11, partial $\eta^2$ =.016. Furthermore, concerning the rate of change across IQ, this was not a significant predictor of performance over all participants $F$ (1, 163) = .001, $p$ = .97, partial $\eta^2$ < .01 and no reliable interaction of Group x IQ, $F$ (1, 163) = .42, $p$ =.52, partial $\eta^2$=.003 was found. As seen in figure 5.3 the two groups' trajectories are almost parallel indicating no reliable IQ-related changes.



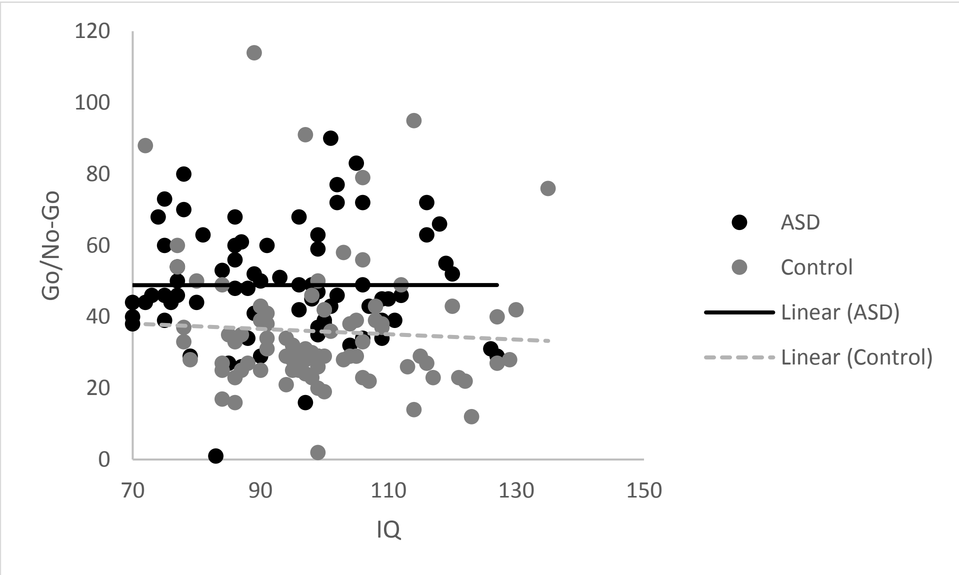




**Figure 5.3. Trajectory of inhibition ability relative to age and IQ for controls and ASD participants.**

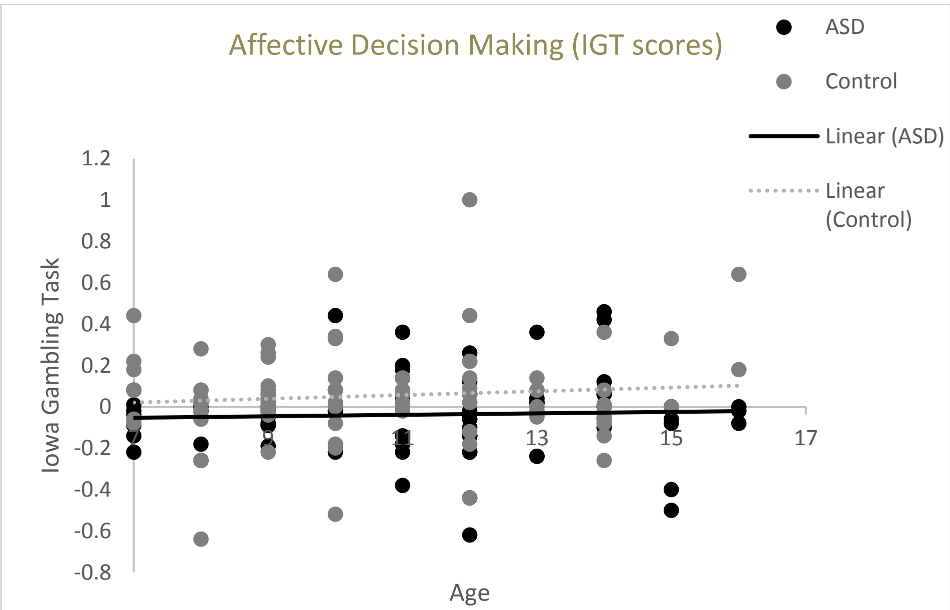
Table 5.3. Intercept and slope of linear developmental trajectories predicting EF and ToM scores based on putative developmental predictors.

| | ASD | | Controls | |
|---|---|---|---|---|
| | **Age** | **IQ** | **Age** | **IQ** |
| Digit Span | m=7.1 (SE= .29) | m=7.25 (SE=.3) | m= 10.89 (SE= .27) | m=10.65 (SE=.28) |
| | b=-3.94 , $r^2$ =.09 | b= .31 , $r^2$ =.18 | b= 5.07 , $r^2$ =.19 | b=6.8 , $r^2$ =.05 |
| Go/No Go | m=49.2 (SE= 1.97) | m=48.99 (SE=2.02) | m=35.67 (SE=1.79) | m=36.1 (SE=1.83) |
| | b= 66.47 , $r^2$ =.06 | b= 44.14 , $r^2$ = .002 | b=47.76 , $r^2$ =.03 | b= 42.00 , $r^2$ = .002 |
| ToL | m= 7.04 (SE= .20) | m= 7.15 (SE=.20) | m= 8.38 (SE=.19) | m= 8.29 (SE=.19) |
| | b= 6.74 , $r^2$ = .001 | b=2.75 , $r^2$ = .11 | b=5.09 , $r^2$ =.2 | b= 7.07 , $r^2$ = .04 |
| IGT | m= -.04 (SE=.024) | m=-.036 (SE=.024) | m= .06 (SE=.022) | m=.05 (SE=.022) |
| | b=-.08 , $r^2$ =.002 | b=-.12 , $r^2$ =.005 | b= -.06 , $r^2$ =.01 | b=-.18 , $r^2$ =.01 |
| Delay Discount | m= .32 (SE=.015) | m=.32 (SE=.015) | m= .38 (SE=.014) | m= .38 (SE=.014) |
| | b= .3 , $r^2$ =.002 | b= .38 , $r^2$ =.006 | b=.45 , $r^2$ = .01 | b=.37 , $r^2$ <.001 |
| Sandbox | m= .81 (SE=.03) | m=.79 (SE=.033) | m= .67 (SE=.02) | m=.69 (SE=.03) |
| | b=1.21 , $r^2$ =.08 | b=.96 , $r^2$ = .007 | b=1.27 , $r^2$ = .27 | b= .76 , $r^2$ = .003 |
| Eyes Test | m= 14.9 (SE=.36) | m=15.37 (SE=.36) | m= 19.12 (SE=.34) | m=18.9 (SE=.34) |
| | b=12.87 , $r^2$ = .02 | b=6.63 , $r^2$ = .13 | b= 16.21 , $r^2$ = .05 | b=17.17 , $r^2$ = .006 |

**5.3.2.2. Cross sectional developmental trajectories: hot executive function**

**Affective decision making** ability was assessed relative to chronological age using the Iowa Gambling Task scores. The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 84 months) as well as within-group trajectory slopes. The intercept of IGT trajectory did not differ significantly between the two groups $F$ (1, 165) = 1.4, $p$ = .24, partial $\eta^2$ = .009, indicating no delayed onset in the ASD group relative to the control group. Chronological age was not a significant predictor of IGT scores $F$ (1,165) = .87, $p$ = .35, partial $\eta^2$ = .005. Finally, there was no significant Group x Age interaction effect, $F$ (1, 165) = .17, $p$ = .68, partial $\eta^2$ = .001. As shown in figure 5.4 for both groups, trajectories are almost parallel and performance did not present significant changes across younger and older participants.

The evaluation of the IGT trajectory against IQ in terms of the intercept took place at the lowest point of overlap between the groups (Wechsler's scale score of 70-the lowest score reported) as well as within-group slopes. There were no significant group differences $F$ (1, 165) = .39, $p$ =.53, partial $\eta^2$ = .002 at the lowest point of overlap. Rate of change across IQ was not a significant predictor of performance, $F$ (1, 165) = 1.73, $p$ = .19, partial $\eta^2$ =.01, nor was there a significant interaction of Group x IQ, $F$ (1, 165) = .44, $p$ =.51, partial $\eta^2$=.003. For both groups there were no significant IQ-related changes (see figure 5.4).



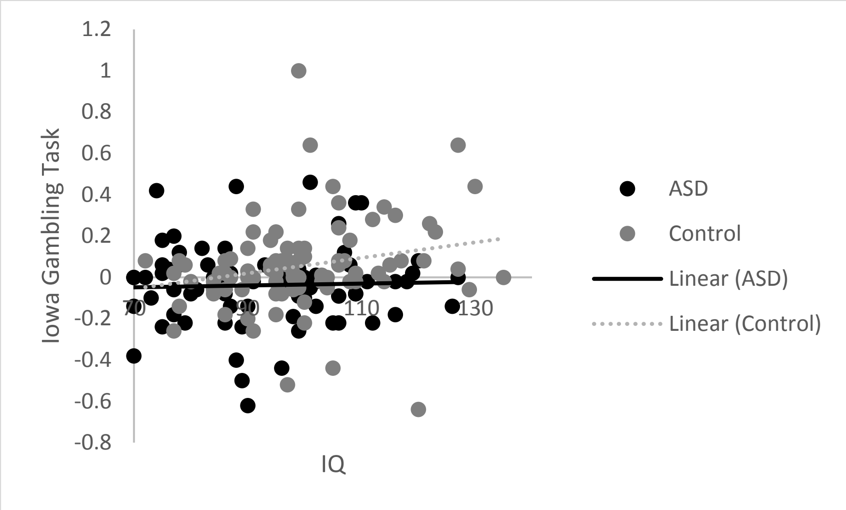
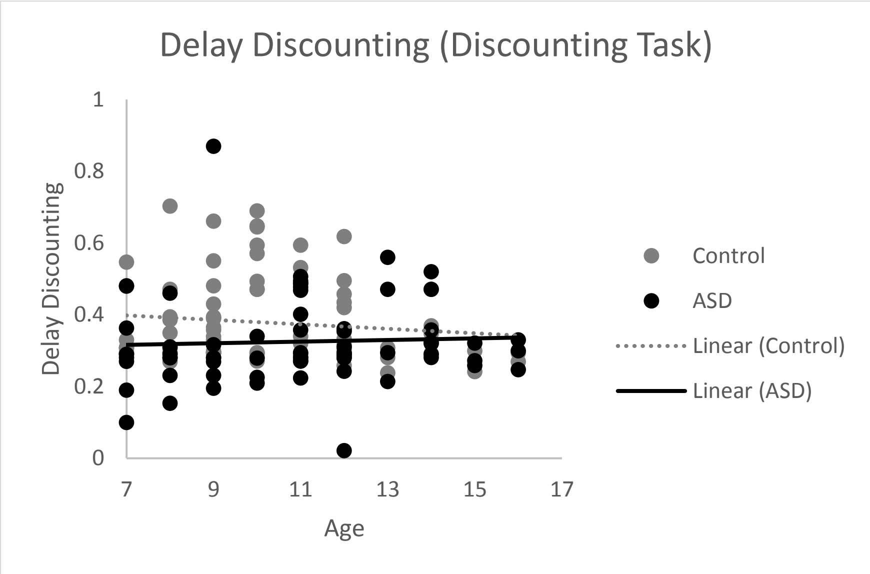



**Figure 5.4. Trajectory of affective decision making ability relative to age and IQ for controls and ASD participants.**

**Delay discounting** was assessed relative to chronological age using the delay discounting scores. The intercept of the trajectory was examined at the lowest age of overlap between the two groups (i.e. 84 months) as well as within-group trajectory slopes. The intercept of delay discounting trajectory differed significantly between the two groups, $F$ (1, 147) = 5.19, $p$ = .024, partial $\eta^2$ = .04. Chronological age was not a significant predictor of the delay discounting scores $F$ (1,147) = .26, $p$ = .61, partial $\eta^2$ = .002, and there was no significant Group x Age interaction effect, $F$ (1, 147) = 1.10, $p$ = .29, partial $\eta^2$ = .008. As shown in figure 5.5, for both groups, performance did not present significant changes across younger and older participants.

The evaluation of the delay discounting trajectory against IQ in terms of the intercept took place at the lowest point of overlap between the groups (Wechsler's scale score of 70-the lowest score reported) as well as within-group slopes. There were no significant group differences $F$ (1, 147) = .47, $p$=.49, partial $\eta^2$ =.003 at the lowest point of overlap. For rate of change over IQ results showed that IQ was not a significant predictor of performance over all participants $F$ (1, 147) = .15, $p$=.7, partial $\eta^2$=.001, and no reliable interaction of Group x IQ, $F$ (1, 147) = .37, $p$ =.54, partial $\eta^2$=.003 was found. For both groups there were no significant IQ- related changes (figure 5.5).



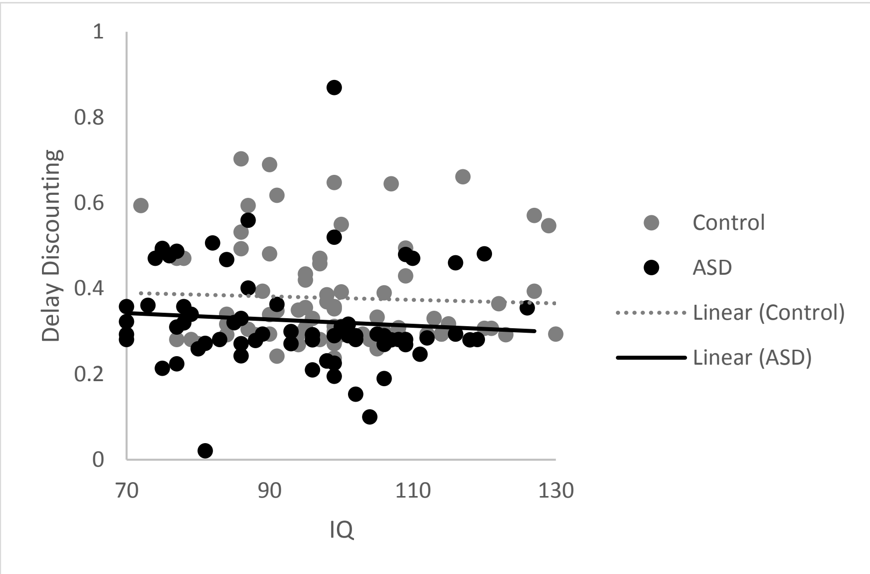
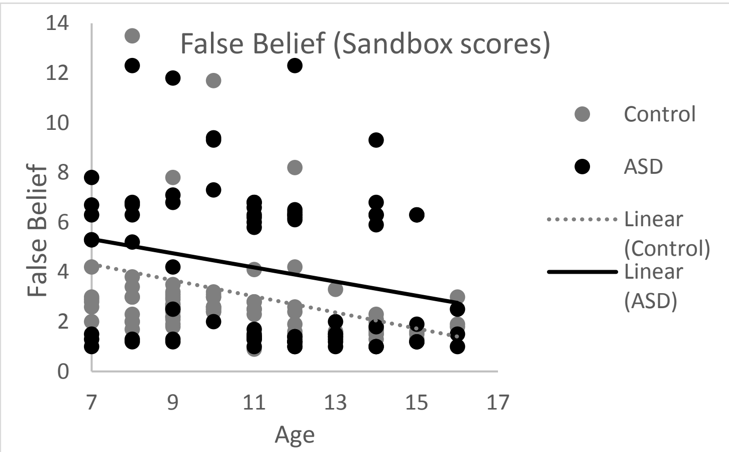




**Figure 5.5. Trajectory of delay discounting ability relative to age and IQ for controls and ASD participants.**

### 5.3.2.3. Cross-sectional developmental trajectories: Theory of Mind

**False belief knowledge** (Note: The lower scores, the better performance in this task)

No significant differences were found between the two groups' intercepts at the lowest point of overlap (i.e. 84 months) [$F$ (1, 168) = .13, $p$=.72, $\eta^2$=.001] (indicating no delayed onset for the ASD group relative to the control group). While chronological age was a strong predictor of performance overall $F$ (1, 168) = 30.51, $p$<.001, $\eta^2$=.16, there was no significant interaction of Group x Age [$F$ (1, 168) = 1.3, $p$= .26, $\eta^2$=.01] found. As shown in Figure 5.6, performance improved with age for both groups. In terms of IQ, there was no significant difference between the two intercepts at the lowest point of overlap (IQ: 70), $F$ (1, 168) = .44, $p$=.51, $\eta^2$=.003. Moreover IQ did not predict performance overall $F$ (1, 168) = .63, $p$=.43, $\eta^2$=.001 and no significant Group x IQ interaction was found $F$ (1, 168) = .1, $p$= .75, $\eta^2$=.001. Figure 5.6 shows that for both groups, performance did not improve with higher IQ scores.



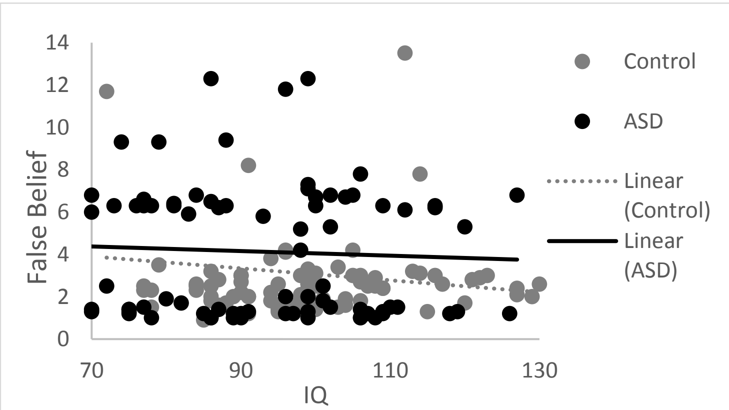




**Figure 5.6. Trajectory of false belief ability relative to age and IQ for controls and ASD participants.**

**Mental state/ emotion recognition**

There was no significant difference between the intercepts of the two groups at the lowest point of overlap (84 months) *F* (1, 158) = 2.18, *p*=.14, $\eta^2$=.014 (no delayed onset). In terms of rate of change, while chronological age was a strong predictor of performance overall *F* (1, 158) = 5.23, *p*=.024, $\eta^2$=.03, there was no significant interaction of Group x Age *F* (1, 158) = .12, *p*= .73, $\eta^2$=.001. As shown in Figure 5.7, performance on this ToM task improved with age in both groups. In terms of IQ, a significant difference was found between the two groups intercepts at the lowest point of overlap (IQ: 70), *F* (1, 158) = 9.07, *p*=.003, $\eta^2$=.06. IQ significantly predicted performance overall *F* (1, 158) = 9.3, *p*=.003, $\eta^2$=.06 while the Group x IQ interaction was also significant *F* (1, 158) = 3.9, *p*= .04, $\eta^2$=.03. For the control group performance on the ToM emotion understanding task was relatively stable across lower and higher IQ scores while for the ASD group performance improved with higher IQ scores (see Figure 5.7)

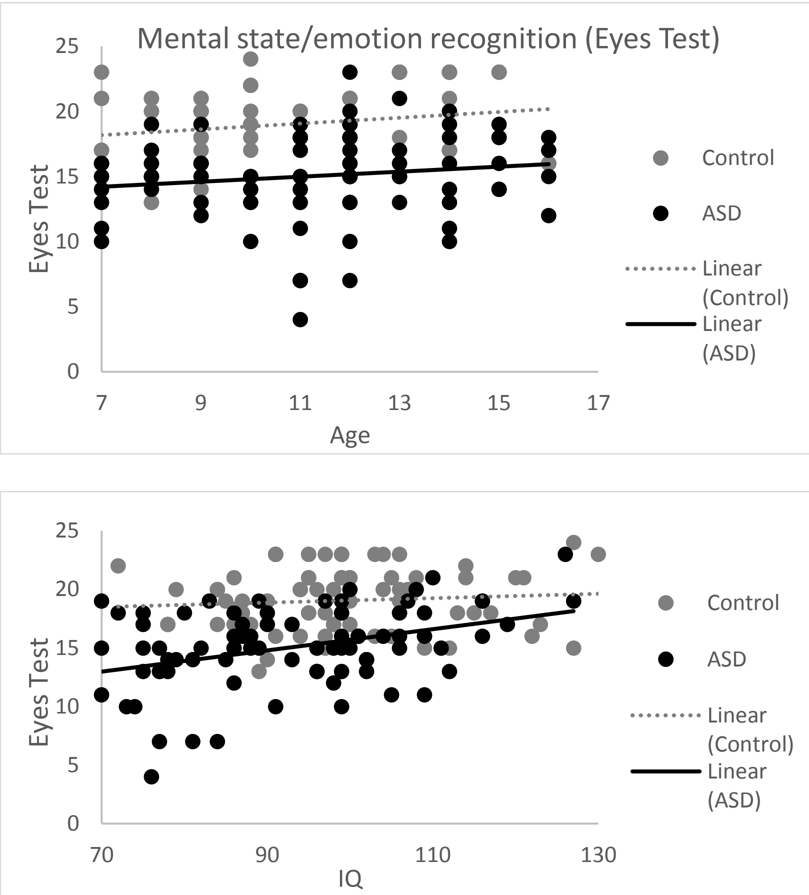



**Figure 5.7. Trajectory of mental state/ emotion recognition relative to age and IQ for controls and ASD participants.**

### 5.3.3. Cool and Hot EF organisation

(See table 5.2) Correlational analyses run separately in the two groups showed that cool EF measures were significantly related to each other in both groups. In the control group, digit span scores were correlated to ToL and Go/No-Go scores while in the ASD group, digit span was related only to ToL. Hot EF measures were unrelated to each other in either group.

Cool and hot EF measures were significantly correlated only in the control group. More specifically, IOWA scores were correlated to Digit Span and ToL scores while delay discounting was related to Go/No-Go scores. No significant associations were found between hot and cool EF in the ASD group.

### 5.3.4. EF-ToM association

The predictive relationship between cool and hot EF and ToM was investigated by running two hierarchical multiple regression analyses to look at the extent to which hot EF scores predicted ToM group differences (*false belief* and *Eyes Test scores*) over and above cool EF and control variables. Dependent variables included the ToM Eyes Test and false belief measures. The regression models included: a) age, IQ, ASD diagnosis and cool EF aspects *(go/no-go, digit span, ToL scores)* on the first block, b) hot EF aspects *(delay discounting* and *IGT scores*) on the second, and c) the hot EF X ASD diagnosis interaction terms, computed from the cross-product of effect-coded ASD (-1=Autistic, +1=Control) and the centred hot delay discounting scores (Aiken & West, 1991), in order to examine whether the association of hot EF to ToM was stronger in either controls or ASD on the third block of predictors.

Table 5.4 indicates that the first step introducing control variables and cool EF contributed significantly to the variance of the ToM false belief ability $F$ (6, 152) = 10.27, $p$ < .001, explaining 21%. ToL ($p$=. 011), and Go/No Go scores ($p$ = .014) significantly predicted ToM false belief scores. Hot EF scores and Hot EF X ASD diagnosis interactions entered on the second and third step accordingly, did not significantly predict ToM false belief ($p_s$ >.41).

Regarding ToM mental state/ emotion recognition (Eyes Test), control variables and cool EF initially explained 29.1% of the variance in Eyes Test scores [$F$ (6, 146) = 15.16, $p$ < .001]. When hot EF was entered in the second step, the total variance explained significantly rose to 34.9%, [$F$ (2, 146) = 6.572, $p$ =.002] as hot EF explained an additional 5.8% of the variance in Eyes Test. Finally, Hot EF x ASD diagnosis interactions entered on the last step did not add any significant variance. ToM scores were significantly predicted by Go/no Go scores ($p$ = .013) and delay discounting ($p$ = .006). Hot delay discounting predicts ToM mental state/ emotion recognition over and above cool EF in children and adolescents with and without ASD.

**Table 5.4. Hierarchical regression analysis for ToM false belief and Eyes Test scores by group and EF variables**

| Predictors | False belief | | EyesTest | |
|---|---|---|---|---|
| | β | $\Delta R^2$ | β | $\Delta R^2$ |
| *Step 1* | | .21** | | .29** |
| Age | 0.5* | | 0.7* | |
| ASD diagnosis | -.044 | | -.065* | |
| FSIQ | .001 | | .06** | |
| Digit Span | -.017 | | .12 | |
| Go/No-Go | .003* | | -.06* | |
| ToL | -.043* | | .35 | |
| *Step 2* | | .001 | | .06** |
| IGT | -.033 | | .47 | |
| Delay Discounting | .011 | | 7.49** | |
| *Step 3* | | .004 | | .09 |
| Hot delay X ASD | -3.2 | | -2.85 | |
| Hot IGT X ASD | .38 | | .46 | |

| | | |
|---|---|---|
| $R^2$ | .22 | .44** |
| *F* test | 5.89 | 16.29 |

Note. *p <. 05, **p < .01

### 5.4. Discussion

In contrast to testing differences in cross-sectional group means, which masks changes associated with age or IQ, the cross-sectional developmental trajectories approach was adopted to avoid the methodological limitations (e.g. no identification of delayed or deviant trajectories) of previous studies on this topic. Building on Study Two, investigation of the hot and cool EF developmental pathways was extended from middle childhood to adolescence. In summary, results showed that only cool EF inhibition presented age-related improvements in the ASD sample while planning and working memory lacked significant developmental gains. Working memory was even found to demonstrate developmental losses in ASD. In terms of IQ, again only cool EF, working memory and planning, presented changes between lower and higher IQ functioning participants in ASD. No age or IQ-related differences were found for hot EF aspects in either group. These results extend findings of Study Two for intact and impaired aspects of developmental progression of distinct EF from middle childhood to adolescence in ASD. For ToM, ASD participants presented improvements with chronological age in both the false belief and mental state/ emotion recognition measures. Finally, the present results suggested that the hot and cool EF measures were not significantly associated in the ASD group and hot EF still predicted ToM mental state/emotion recognition over and above cool EF in ASD and typical development.

### 5.4.1. Cool and hot EF developmental trajectories

Results documented a developmental pattern of increases and a linear age trend in working memory, for the typically developing participants, consistent with Study Two. The developmental trajectory of working memory of children and adolescents with ASD differed as a function of chronological age but not IQ, relative to the control group. Even though at the age of onset (7 years of age) there were no differences between the two groups, there was a developmental progression of working memory impairments across age in ASD. The lack of significant age improvements in verbal working memory is in line with recent reports of developmental arrest in verbal working memory in ASD (Andersen et al., 2014). These data could not reveal whether this decrease in working memory capacity is present across adulthood or whether maturation occurs in later adolescence/early adulthood, as only participants between 7-16 years were included. Building on the results from Study Two, this pattern of *deviant* development suggests that working memory may not demonstrate further developmental improvements beyond middle childhood in ASD. Unlike typically developing peers who exhibit developmental gains across middle childhood and adolescence, the ASD group's deficient performance seems to deteriorate in adolescence in ASD. Such a developmental pattern could be explained by previous limited research demonstrating that working memory impairments might increase with age within ASD, likely due to a higher load for manipulation of working memory information (Travers et al., 2011). Another potential explanation regarding the working memory performance losses in ASD may lie on the particular IQ distribution of the ASD sample. In contrast to age-related losses, the ASD group's performance improved with higher IQ scores. The significant positive association between intelligence and working memory is well established in the literature, as working memory is argued to represent the "dynamic tradeoff" between the processing and storage of information, required in complex measures of intelligence and high-order cognition in general (Unsworth et al., 2014). Indeed, high IQ scores are linked to more robust working memory capacity (Alloway et al., 2009). After the inspection of the IQ scores within the ASD group, it was found that the older participants (12-16 years) had lower IQ scores compared to the younger ones (7-11 years). Adolescents' lower IQ ability was positively related to lower working memory ability, whereas younger children's higher IQ performance allowed for a more competent working memory capacity. This particular IQ distribution of the sample could explain why the age-related developmental trajectory of verbal working memory progressively presented impairments across adolescence. Luna et al. (2007) suggests that if impairments appear later in the development, as in the present case (early adolescence), that could imply that the developmental transition and underlying brain maturation mechanisms regulating verbal working memory (e.g. dorsolateral prefrontal cortex/ left temporo-frontal cortex) might be deficient in adolescence in ASD.

With regards to planning, results of the control group were consistent with Study Two and previous reports of significant developmental changes throughout middle childhood and adolescence (Huizinga et al., 2006; Korkman et al., 2001). Despite the lack of deficits at the age of onset (7 years), no significant age-related improvements were found across development in ASD, which in a way reveal a *deviant* to controls developmental pattern. Building on findings of Study Two it seems that planning may reach a performance ceiling in middle childhood, which does not allow for further improvements in adolescence. The poorer performance in planning may emerge during the developmental transition from primary to secondary settings where demands of the environment are higher. These findings contradict Chen et al.'s recent study (2016) showing that planning deficits in ASD as measured by Cantab's Stockings of Cambridge (SOC) were significant in childhood but would lessen with age. One possible explanation could be their participants exhibiting superior IQ scores (>10 points higher) relative to the present study, while their significantly larger ASD sample size (n=114) could have also allowed-in terms of statistical power- for the detection of subtle developmental changes. As the poorer -to controls- planning performance of ASD becomes apparent later in the development (adolescence), it is suggested that the developmental transition from childhood to adolescence might be impaired for the underlying brain regions (i.e. dorsolateral prefrontal cortex) of planning skills (Luna et al., 2007) in ASD. Finally, the demonstration of planning scores improving with higher IQ scores is in line with previous studies reporting such significant association between intelligence and planning in ASD (Kimhi et al., 2014; Pellicano, 2007, van Eylen et al., 2015) and typical development (Arffa, 2007), as they are both core cognitive constructs contributing mutually towards the development of self-regulation.

Results showed that inhibition improved with age but not with higher IQ scores in either group. The steady pattern of improvements from age 7 to 16 for controls, corroborate reports of response inhibition tasks (i.e. Go/No-Go), following advances not only during early and middle childhood (Carlson et al., 2013; Carlson & Moses, 2001; Romine & Reynolds, 2005), but beyond 10 years as well (even more subtle) (Best & Miller, 2010). Most importantly, the significant age-related improvements reported in the ASD group, in line with Study Two and previous studies (Happé et al., 2006a; Luna et al., 2007; van Eylen et al., 2015), paint a more positive picture of autistic children's particular cognitive developmental trends, indicating perhaps the likelihood of a window of plasticity, beyond middle childhood, in ASD as well. It should be noted however that the ASD group indicated a lower performance at the age of onset (7 years) which remained present throughout development in ASD without reaching the levels of neurotypicals (*deviant* development). Data failed to provide more evidence about the maturity peak of inhibition in ASD (if they ever develop up to the same level as controls) as it did not include older adolescents or young adults. However, looking at these significant continuing improvements in inhibition, in both Study Two and Three, from the maturation processes perspective of Luna et al. (2007), it could be implied that impairments in the underlying brain mechanisms (i.e. dorsal areas of the lateral prefrontal cortex) of inhibition, are not related to the brain developmental/ maturation processes (that may be intact for ASD participants). The age-related improvements of inhibition in our ASD sample highlight the importance of implementing interventions aimed at augmenting self-control (inhibitory control) within ASD. The lack of significant developmental relationship between IQ and inhibition is in line with previous research investigating such association in school age in Attention-Deficit/Hyperactivity Disorder (ADHD) (Bitsakou et al., 2008; Rubia et al., 1998) and typical development (Lee et al., 2015) suggesting that intelligence does not explain any inhibition variance in ASD either.

Study Three was the first study to date to examine the development of hot EF in ASD across childhood and adolescence. Contrary to the findings for cool EF, hot EF demonstrated non-significant age related changes in both typical development and ASD. The assumption made in Study Two, trying to explain the lack of developmental gains in delay discounting in middle childhood, suggested that this hot EF ability perhaps experiences a developmental plateau in middle childhood and may improve again in adolescence. However, the lack of significant performance gains in delay discounting in this study as well, failed to provide support to that view. Findings from both studies overall contradict previous research in typical development (Scheres et al., 2006; Scheres et al., 2014), showing that children discounted rewards more steeply (lower performance) than older adolescents. As already discussed in Study Two, methodological differences and task discrepancies may have accounted for these inconsistencies. For example, Scheres et al. (2006) used a temporal and probabilistic discounting task with smaller magnitudes of the immediate monetary reward (0, 2, 4, 6, 8, or

10 cents), shorter delays (0, 5, 10, 20, or 30 seconds) as well as probability levels of the large reward (more complex task) and a smaller number of trials. Their monetary awards were real rather than hypothetical and participants were paid a small amount of money after the practice trials (reinforcers). These important differences may have resulted in their older participants being more motivated to wait for the larger rewards relative to older participants in the current study. It should be also noted that different hot EF measures seem to vary in motivational and emotional significance due to different designs or requirements; thus participants may vary in their performance or subtle developmental changes may be masked. As several measures of hot EF have been criticised for lacking enough "heat" or not being ecologically valid (Welsh & Peterson 2014), one could argue that the hot EF tasks as used in this study (e.g. the Delay Discounting was modified to lack the probability questions) were not really 'hot' for the age group used here. For example, considering differing quantities of imaginary money is quite an abstract construct that may have failed to enhance younger children's motivation or led the older participants reaching a performance ceiling.

Expanding on the findings of Study Two, in which young children presented performance improvements in the IGT (affective decision making), a possible explanation for the older participants not making choices that are more advantageous over the younger ones on the IGT in this study could be the hypothetical awards not increasing their sensitivity to money loss or enhancing their desire to win. Indeed, Xu et al. (2016) very recently found that participants would demonstrate reduced risk taking in gambling tasks (tapping affective decision making) after money loss when the monetary awards were real relative to those receiving hypothetical rewards, suggesting amplified loss aversion (focus on avoiding losses rather than receiving gains) with real monetary awards. Finally, as this is the first study to investigate the development of both hot and cool EF from childhood to adolescence in ASD, it could be suggested that selective hot EF aspects such as delay discounting are likely to present rapid changes only during the preschool period (and not later on) in ASD, while others (i.e. affective decision making) may present improvements up to middle childhood and not during adolescence. Future longitudinal studies with several time points across middle childhood and adolescence in ASD are needed to clarify this issue.

### 5.4.2. Cool and Hot EF organisation

Following the different developmental trends for hot and cool EF found in the ASD group, different patterns of relations were also found among the cool and hot EF measures in the two groups. Developmental theories that suggest the distinction between hot and cool EF (Zelazo & Müller, 2002), argue that cool cognitive EF is regulated by lateral inferior and dorsolateral frontoparietal mechanisms (Miller & Cummings, 2007) while hot affective EF is mediated by the paralimbic orbitomedial and ventromedial frontolimbic structures (Fuster, 1997). Distinct neural regulations could allow for distinct developmental pathways. Generally, the association between cool and hot EF is still debated and very little is known about their organisation in ASD. Cool EF skills were positively associated with each other in both groups across development, suggesting that better performance in one aspect of cool EF relates to better scores in another cool measure. This evidence supports well-documented theories distinguishing EF into separate, yet interrelated subcomponents (Miyake et al., 2000). These results also supported the findings of Hongwanishkul et al. (2005) that showed that the association among various cool EF skills is strong across early childhood, by further expanding this relationship across middle childhood to adolescence not only in neurotypicals but ASD participants as well. However, with respect to hot EF, both delay discounting and affective decision making were unrelated to one another in either group, suggesting that these measures may possibly be underpinned by different hot regions. For example, affective decision making, as tapped by the Iowa Gambling task (Bechara et al., 1994) is argued to capture performance that cannot be linked to cognitive abilities such as executive functions (neither hot nor cool) or intelligence (Toplak et al., 2010). Research investigating the internal association of hot and cool EF is still in its infancy and as a result, knowledge of the organisation of hot EF lags behind that of cool. More research is needed to clarify this issue.

Interestingly, the association between hot and cool EF was significant only in the control group. Consistent with the hypothesis stated, affective decision making was significantly correlated to cool working memory and planning in line with previous studies investigating such a relationship in adulthood (Brand et al., 2005; Hinson et al., 2003). There is evidence though suggesting that performance on hot EF gambling tasks is independent of performance on cool EF measures, including working memory, in adults (Fonseca et al., 2012) and young childhood (O’Toole et al., 2016). These results add to the ongoing debate in typical development by suggesting that affective decision making and cool EF are associated across childhood and adolescence. Hot delay discounting exhibited associations with cool EF (in the control group) also suggesting that cool EF skills may possibly be used in cases of emotionally or motivationally significant problem solving (Zelazo et al., 2005). Overall this evidence shows that during childhood and adolescence within typical development, hot and cool EF may not necessarily be considered as separate constructs always (Allan & Lonigan, 2014). No correlations between hot and cool EF were found in ASD, suggesting that hot and cool EF could be dissociable functions in ASD. Generally, it is suggested that cool and hot EF aspects could differentiate from each other across development, extending early childhood (Diamond, 2006). However, these results show that the internal EF organisation may represent a multidimensional model distinguishing between hot and cool only in the ASD group, but a unitary construct (Allan & Lonigan, 2014) in typical development. More research using factor analysis in ASD is needed though, in order to clarify whether cool and hot EF are truly representing distinct domains or a unitary construct, simply used differently under abstract and emotionally/motivationally significant situations in problem solving.

### 5.4.3. ToM developmental trajectories and association to EF trajectory

The present results showed that both controls and ASD participants exhibited age-related improvements in ToM measures across adolescence, expanding the positive results from Study Two that found that ToM made substantial progress across middle childhood. These findings suggest that ToM abilities continue to develop during adolescence as well, in ASD and typical development. Taking this developmental data together (Studies Two and Three), more support is provided to previous neuroimaging evidence having shown that specific brain regions underlying mental state attribution (i.e. medial prefrontal cortex and lateral temporo-parietal regions), present both structural (Shaw et al., 2008) and functional (see for a review, Blakemore, 2008) developments across middle childhood and adolescence. As other studies have found no age-related improvements in ToM measures across ASD, (Ozonoff & McEvoy, 1994; Holroyd & Baron Cohen, 1993), it could be assumed that the tests addressed in the present thesis were more developmentally sensitive for this group. For example, the false belief Sandbox task (Begeer et al., 2012) has been claimed to be sensitive enough to capture subtle false belief difficulties in participants with ASD who are able to successful pass classic false belief measures (Apperly, et al., 2011; Begeer et al., 2012). In addition, the studies (Paynter & Peterson, 2010; Steele et al., 2003) that reported age-related ToM improvements in ASD, including the present study, sampled participants with high functioning ASD. Participants with higher IQ scores are more likely to demonstrate more significant ToM improvements than a low-functioning population. It should be noted that these developmental patterns may in reality reflect the ongoing maturation of the functional relationship between EF and ToM. The findings of the regressions run to investigate the association between ToM and EF corroborated previous reports of associations between cool EF and ToM in young childhood and middle childhood in ASD (Pellicano, 2007; Kimhi et al., 2014; Ozonoff et al., 1991). They also expanded the findings of Study Two by suggesting that EF and ToM still share a developmental relationship beyond middle childhood. More specifically, ToM false belief and mental state/ emotion recognition were predicted by cool EF suggesting that participants with and without ASD who for example performed better on tasks such as the Go/No Go or Tower of London, could more easily disengage from their own emotional/mental states or suppress irrelevant ones, when inferring another's emotions or beliefs. Moreover, these findings further expanded this relationship indicating that the hot EF aspect of delay discounting predicted ToM mental state/ emotion recognition over and above cool EF and control variables, similar to Studies Two (Chapter 4) and One (Chapter 3). Participants with and without ASD who were less impulsive and chose larger delayed rewards demonstrated superior performance on the Eyes task. Explanations of why these two constructs may relate have already been discussed in depth in Chapters Two and Four. Under this theoretical framework, it could be assumed that the development of a balanced time perspective of adolescents with and without ASD is somehow still associated with emotion functioning across adolescence.

The present study was the first study to date to assess the cross-sectional developmental trajectories of hot and cool EF and ToM in children and adolescents with and without ASD, in contrast to traditional group means comparison, as this methodology can reveal important information about delayed onsets and slower rates of development between the trajectories. Contradicting the specific developmental EF improvements of Study Two, Study Three showed that most EF skills no longer presented significant performance gains in adolescence in ASD. Cool and hot EF however still shared a significant developmental association with ToM in both groups. The development of EF so far has been examined using only performance-based neuropsychological measures. The significant heterogeneity of ASD as clearly shown in the three first studies highlights the importance of assessing the development of distinct EF domains, not only at the level of the cool and hot EF subsystems, but also from an ecologically valid perspective, using real world EF scales. Study Four built on the present study by using the same cross-sectional developmental trajectory approach to explore the developmental pathway of “real-life” EF (as reported by teachers) of the participating children and adolescents with and without ASD of Study Three.

# CHAPTER VI

## Study 4. “REAL-LIFE” EXECUTIVE FUNCTION AND ADAPTIVE SKILLS IN CHILDREN AND ADOLESCENTS WITH AND WITHOUT AUTISM SPECTRUM DISORDER: CROSS-SECTIONAL DEVELOPMENTAL TRAJECTORIES AND COMPARISON TO PERFORMANCE-BASED EF MEASURES


### Abstract

The development of EF in ASD has been so far investigated in this thesis using only performance-based EF measures. Less is known about the developmental patterns of “real-life” EF ratings as reported by teachers in schools. Moreover, the two types of EF measures are argued to tap different constructs implying that they should not be used interchangeably in clinical research. Building on Study Three, the present study used the same cross-sectional developmental trajectory approach aiming to identify the developmental pattern of “real-life” EF (as reported by teachers) of children and adolescents with ASD compared to typically developing peers. This is the first study to compare the developmental trends of both “real-life” ratings and performance based EF tasks and investigate the predictive relation between both types and adaptive skills in children and adolescents with and without ASD. Results showed age-related performance declines in several “real-life” EF domains in ASD (i.e. inhibition, initiate, working memory, planning, organisation, self-monitoring) whereas for EF emotional control and shift, non-significant differences emerged across age in ASD. These results, taken together, suggest that the vast majority of “real-life” EF problems mainly increase in adolescence. Moreover, it was found that the “real-life” EF cross-sectional developmental trajectories deviated from those of typical development and most importantly that the developmental pathway for some “real-life” EF aspects (inhibition and planning) were different compared to the performance-based EF profiles of those aspects presented in Study Three (Chapter5). Finally, it was found that only “real-life” and not performance-based EF predicted adaptive skills over and above age and IQ in children and adolescents with and without ASD. This evidence provides support to the notion that “real-life” EF may actually measure different underlying cognitive constructs.

**Chapter Overview**. The present study built on study Three as it compared the developmental trajectories of the two types of EF measures, "real-life" ratings and performance-based EF tasks (as tapped by the direct neuropsychological assessment of participants in Study Three), especially focusing on which type was the strongest predictor of adaptive skills in children and adolescents with and without ASD.

## 6.1. Introduction

As already discussed in the previous chapters, the executive dysfunction theory posits that several autism manifestations, especially the social deficits, may arise from disruptions in EF (Damasio & Maurer, 1978; Pennington & Ozonoff, 1996). Although several studies have reported EF deficits across the lifespan in ASD (Corbett et al., 2009; for reviews see Hill, 2004; Russo et al., 2007) children and adolescents with ASD seem to evolve in their EF abilities (Christ et al., 2011; Happe´ et al., 2006; Pellicano, 2010) or even present intact EF profiles (Hill & Bird, 2006; Towgood et al., 2009). Thus the development of EF in ASD seems to present significant heterogeneity, highlighting the importance of assessing the development of the different EF domains separately, not only at the level of the cool and hot EF distinction but also between performance-based and "real-life" rating scales of EF.

Due to the increasing attention EF has received while being investigated from a cognitive psychological perspective, researchers have developed ecologically valid measures in order to assess EF abilities in real world contexts. To date only a few scales have been designed to tap everyday EF difficulties including ratings such as the Childhood Executive Functioning Inventory (CHEXI; Thorell & Nyberg, 2008), the Dysexecutive Questionnaire for Children (DEX-C; Emslie, Wilson, Burden, Nimmo-Smith, & Wilson, 2003) and the Child Behavior Questionnaire (CBQ; Rothbart, Ahadi, Hershey, & Fisher, 2001). BRIEF is a valid and reliable measure of EF performance in everyday settings (i.e. classroom) (e.g., Kenworthy, Yerys, Anthony, & Wallace, 2008; Mahone et al., 2002; Mangeot et al., 2002; Nadebaum, Anderson, & Catroppa, 2007; Toplak, Bucciarelli, Jain, & Tannock, 2008) and widely used in clinical research as it has been found to share a strong relationship with several other teacher/parent-report behaviour ratings in clinical populations generally (Child Behavior Checklist – Parent version; Achenbach, 1991; Diagnostic Interview for Children and Adolescents; Reich, 2000). However, it should be noted that there have been very low or even non-significant correlations of BRIEF with performance-based tasks of EF (i.e. Anderson,

Anderson, Northam, Jacobs, & Mikiewicz, 2002; Bodnar, Pralune, Cutting, Denckla, & Mahone, 2007; Mahone et al., 2002).

This evidence raises questions about the nature of those two seemingly similar measures and appears to indicate that performance-based tests and rating scales may tap different constructs of the multifaceted EF system (McAuley et al., 2010; Toplak et al., 2008). According to Kenworthy et al.'s (2008) proposition, which questions the ecological validity of the performance-based measures, the manifestation of EF problems in everyday life are present even in cases of intact EF profiles as measured by performance laboratory measures. Caution should be taken though when stating that parent/ teacher-report EF ratings measure actual EF because the behavioural outcomes measured by ratings such as the BRIEF occur in social contexts and relate to individuals' everyday lives. It is important thus to study these EF behavioural manifestations from a developmental perspective in order to shed more light on the heterogeneity of the developmental profiles of children and adolescents with ASD.

Generally the most dominant theoretical accounts regarding the development of EF in ASD suggest that the developmental pattern followed in ASD could be : a) delayed relative to the typical one (Christ et al., 2011), (b) deviant from typical development (Ozonoff & McEvoy, 1994) or (c) delayed in childhood and deviant in adulthood (Luna et al., 2007). In fact results from Studies Two (Chapter 4) and Three (Chapter 5) of the present thesis showed that the development of EF in children and adolescents with ASD mainly follows a deviant to controls trajectory as their performance never reached that of the typically developing peers despite the age-related gains. Moreover, EF structure appears to become more differentiated with age (Huizinga et al., 2006; Miyake et al., 2000) while different EF systems (i.e. hot and cool) present a different developmental pattern or pace (Best et al., 2009). It would be crucial to focus on specific and more specialised domains of EF rather than the broad construct of EF as a whole. The comparison of different trajectories of several EF components could reveal new patterns and mechanisms of development as it may identify a neuropsychological model derived from in-detail, fractionated brain-based profiles of development. There is however very limited knowledge about the developmental pathway followed by "real-life" EF aspects across childhood and adolescence in ASD. The present chapter thus aims to investigate the developmental profiles of EF in children and adolescents with ASD as rated by the everyday life observations of their teachers within the classroom.

Previous evidence has indicated that children and adolescents with ASD present impairments on the BRIEF items, as rated by their teachers or parents (Chan et al., 2009; Endedijk et al., 2011; Kalbfleisch & Loughan, 2012; Yerys et al., 2009; Zandt et al., 2007). Moreover, several studies have shown that deficits on the BRIEF Behavioural Index (including the EF aspects of inhibition, shift, and emotional control) were correlated with impairments in communication and restricted-repetitive behaviours of individuals within the spectrum (Kenworthy et al., 2009) in line with relevant established associations between performance-based EF measures and ASD symptoms (i.e. cognitive flexibility with repetitive behaviours) (Yerys et al., 2009). It seems thus that despite the weak correlations between performance-based EF and “real-life” EF ratings, the autism phenotype is linked to EF measured by both neuropsychological tests and reported problems in everyday life. The vast majority of previous studies have only used the traditional EF domains of inhibition, planning, shift, and working memory of BRIEF or the composite Index scores: Behavioural Rating Index (BRI) and Metacognition Index (MI) which consider various different EF domains as united composite scores (opposite to the fractionated approach used in this thesis). Thus, the present study focused on all eight distinct EF domains of the BRIEF (inhibition, shift, emotional control, initiate, working memory, planning, organisation, and monitor) in an attempt to shed more light on the multifaceted developmental profiles of “real-life” EF abilities.

As already discussed in Chapter One, knowledge regarding the developmental trends of the BRIEF EF aspects in typical development and ASD is limited. Huizinga and Smidts (2010) reported that “real-life” EF difficulties of typically developing children mainly decreased over time and with age. Results from the few ASD studies though are quite mixed. Rosenthal et al. (2013) for example showed that deficits in BRIEF working memory increase in adolescents with ASD as reported by parents, while van den Bergh et al. (2014) reported no age-related improvements in working memory (BRIEF) of children and adolescents with ASD. Different developmental patterns were evident for all the employed BRIEF subdomains (e.g. inhibition, shift, planning) between the two studies. Taking the evidence of these two ASD studies together, it seems that there is not a clear conclusion regarding the developmental pattern of these EF aspects rated by BRIEF in children and adolescents with ASD. Moreover, findings from these studies seem to also contradict the evidence from the third chapter of the present thesis showing that the developmental trends of the same EF aspects (working memory, planning, & inhibition) as measured by laboratory neuropsychological tasks, were found different in ASD.

## EF and Adaptive Skills

Everyday skills that are considered to tap adaptive behaviours are effective communicative skills, engagement with the community as well as the development of social relations (Klin et al., 2007). The Vineland Adaptive Behaviour Scales (VABS, Sparrow et al., 1984; VABS-II, Sparrow et al., 2005) is the most widely used measure of such adaptive behaviour in childhood and adolescence in ASD and mainly focuses on communication, socialisation, and daily living skills. With regards to the developmental course of adaptive skills in ASD, several cross-sectional studies have found that mainly adaptive communication and socialisation but daily living skills too (to a smaller extent) present age-related losses (Duncan & Bishop, 2013; Kanne et al.,2011; Klin et al., 2007; Pugliese et al., 2015).

EF has been found to be strongly related to adaptive skills in line with findings from the first three chapters of the present thesis that suggested that EF plays a crucial role in the socio- cognitive (e.g. ToM) deficits in this population. Gilotty et al. (2002) showed that selective BRIEF EF subscales (initiation, working memory, planning, organisation, and self-monitoring) were significant predictors of adaptive communication and socialisation in young people with ASD. Pugliese et al. (2015) also showed that BRIEF EF subscales predicted all three adaptive skills (communication, daily living and socialisation) over and above demographic variables and IQ in youth with ASD. Considering the fact that there are reports of age-related changes in the developmental course of EF in ASD (e.g. Rosenthal et al., 2013), it would be crucial to account for EF when predicting adaptive skills across age. Furthermore, the few studies that examined such predictive relation and were described above, have only employed the BRIEF EF subscales. The present study thus attempted to investigate which one of the two types of EF (performance -based and teacher report ratings of EF) was the strongest predictor of adaptive skills in ASD.

### *Current objectives*

The first aim of the present study was to investigate the developmental profiles of “real-life” EF domains in children and adolescents with ASD (7–16 years) relative to neurotypical controls. Instead of focusing only on the specific four, traditionally used, “real-life” EF aspects of inhibition, planning, working memory and shift, all eight EF subdomains of BRIEF were employed, in an attempt to shed more light on the heterogeneity of the developmental course found within the multifaceted construct of EF. Due to mixed results from previous developmental studies using the BRIEF, specific predictions cannot be made. The main focus lied on comparing the developmental patterns of "real-life" EF with the relevant performance-based EF reported in Study Three.

The second aim of the present study was to examine the predictive association between both domains of EF (performance-based and teacher-report EF ratings) and adaptive skills in ASD. Based on evidence presented above (Pugliese et al., 2015; Rosenthal et al., 2013), it was hypothesised that adaptive skills would mainly show age-related declines in ASD and that "real-life" EF domains would also predict adaptive skills. It was sought to specifically determine whether only teacher-report or performance-based EF as well could be significant predictors of adaptive skills in ASD.

## 6.2. Methods

### 6.2.1. Participants

Fifty seven children and adolescents (57) with ASD (*M*=10.40 years, *SD*=2.35) and sixty three (63) controls (*M*=10.03 years, *SD*=2.11) aged 7-15 years old, of the same cohort as Study Three, participated in the present study. Participants with and without ASD fulfilled the same inclusion criteria as the previous studies. Participants were matched for chronological age ($t\ (120) = -.91$, $p = .36$) and IQ ($t\ (120) = 1.79$, $p = .18$).

### 6.2.2. Measures

**EF. *Behaviour Rating Inventory of Executive Function – Teacher Report (BRIEF-TR; Gioia et al., 2000).***

In order to assess the "real-life" EF abilities of participants, teaching staff (teachers and teaching assistants) completed the BRIEF-TR for each child in their class participating in the study. The BRIEF measured two broad areas of EF: *behavioural regulation,* the ability to shift and modulate emotions and behaviour via appropriate inhibitory control; and *metacognition*, the ability to cognitively self-manage tasks and monitor performance. This scale offered the advantage of sampling multiple EF processes (inhibition, shifting, emotional control, initiation, working memory, planning, organisation, and monitor) across a wide age range (5–18 years). Teaching staff rated how true each statement describing children's behaviour over the past 6 months. Numbers that correspond to each rating (i.e., 1 for Never, 2 for Sometimes, and 3 for Often) were then summed for each scale obtaining a raw score. Raw scores were converted into T scores separately for boys and girls. Higher scores indicated poorer performance.

**Adaptive Skills.** ***Vineland Adaptive Behaviour Scales (VABS-T; Sparrow et al., 2005)***.

Teaching staff also completed the Adaptive Behaviour Scale of the VABS-T for each child from their class who participated in the study. The VABS assesses adaptive behavioural skills in socialisation, communication, and daily living of individuals. Raw scores were summed to create composite scores. Teachers rated how true each statement was on a 2-point Likert scale, with ‘0’ meaning ‘never’, ‘1’ meaning ‘sometimes or partially’, and ‘2’ meaning ‘usually’. Standard scores were obtained for each domain. Higher scores suggest better adaptive skills.

### 6.2.3. Statistical Analysis

Preliminary analysis: Group differences for every EF aspect of BRIEF were assessed by running a series of ANOVAs. Main Analysis: The cross-sectional developmental trajectories approach (Thomas et al., 2009) of Study Three was also used here, in order to assess the developmental trends of each BRIEF EF aspect, relative to chronological age. This procedure evaluates the differences between the slope and intercept of the lines depicting the developmental trajectory of each group rather than comparing the cross-sectional group means. The main effect of group (ASD or control), main effect of predictor (chronological age) and the interactions between group and slope were investigated.

## 6.3. Results

### 6.3.1. “Real-life” EF (BRIEF) impairments in ASD

Group differences were investigated by conducting ANOVAs for each EF aspect of the BRIEF measure in order to assess the average group differences of “real-life” EF. Significant group differences were found between the two groups performances on: Brief_Inhibition ($F$ (1, 120) = 32.89, $p$ < .001, $\eta^2$= .22), Brief_Shift ($F$ (1, 120) = 42.11, $p$ < .001, $\eta^2$= .26), Brief_Emotion ($F$ (1, 120) = 55.66, $p$ < .001, $\eta^2$= .32), Brief_Initiate ($F$ (1, 120) = 68.01, $p$ <

.001, $\eta^2$= .37), Brief_working memory ($F$ (1, 120) = 90.09, $p$ < .001, $\eta^2$= .43), Brief_ Planning ($F$ (1, 120) = 56.07, $p$ < .001, $\eta^2$= .32), Brief_Organisation ($F$ (1, 120) = 116.03, $p$ < .001, $\eta^2$= .49), and Brief_Monitor ($F$ (1, 120) = 50.28, $p$ < .001, $\eta^2$= .29). The ASD group showed significantly poorer performance in each hot and cool EF task relative to the control group (see Table 6.1 for Means and SDs).

**Table 6.1. Means and SDs of BRIEF EF aspects for ASD and control groups**

| | Group | | | | |
|---|---|---|---|---|---|
| | ASD ($n$ = 57) | | Control ($n$ = 63) | | |
| EF Domain | *M* | *SD* | *M* | *SD* | *d* |
| Brief_Inhibition | 16.43 | 4.94 | 11.87 | 3.74 | -1.05 |
| Brief_Shift | 13.94 | 3.11 | 10.71 | 2.32 | -1.19 |
| Brief_Emotion | 16.85 | 4.37 | 11.35 | 3.71 | -1.36 |
| Brief_Initiate | 14.69 | 4.36 | 9.07 | 3.04 | -1.51 |
| Brief_WM | 17.91 | 4.61 | 11.30 | 2.91 | -1.73 |
| Brief_Planning | 20.81 | 5.75 | 13.53 | 4.88 | -1.37 |
| Brief_Organisation | 11.56 | 2.16 | 7.63 | 1.84 | -1.96 |
| Brief_Monitor | 14.47 | 3.39 | 10.75 | 2.29 | -1.23 |

Note. Lower scores indicate better performance; *d*: Cohen's d effect size.

**6.3.2. Cross-sectional developmental trajectories of "real-life" EF relative to age.**

**Brief_Inhibition.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_inhibition were not significantly different between the two groups, $F$ (1, 119) = .24, $p$=.62, partial $\eta^2$=.002 at the lowest age of overlap. Regarding the rate of developmental change, chronological age was not a significant predictor of the brief_inhibition scores, $F$ (1, 119) =.31, $p$=.58, partial $\eta^2$ = .003. However, it was found that there was a significant cross over (Group x Age) interaction, $F$ (1, 119) = 12.58, $p$= .001, partial $\eta^2$=.09. Figure 6.1 show that for the control group, brief_inhibition scores improved with age while for the ASD group there was a significant trend for brief_inhibition to worsen with chronological age.

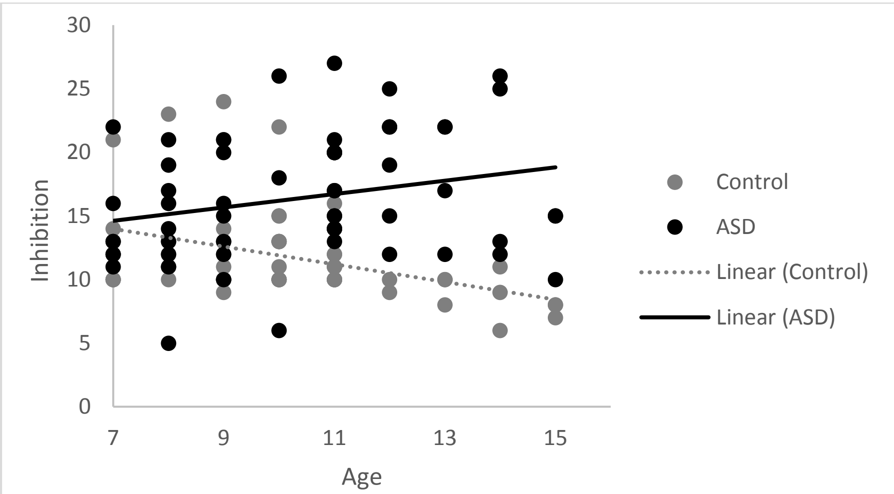



**Figure 6.1. Trajectory of "real-life" inhibition relative to age for controls and ASD participants**

**Brief_Shift:** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_shift were significantly different between the two groups, $F$ (1, 119) = 7.53, $p$=.007, partial $\eta^2$=.06 at the lowest age of overlap. Regarding the rate of developmental change, neither chronological age [$F$ (1, 119) = 1.77, $p$ =.19, partial $\eta^2$ = .02] nor the Group x Chronological Age interaction [$F$ (1, 119) = 1.52, $p$ = .22, partial $\eta^2$=.01] were found significant. Figure 6.2 show that both groups presented non-significant age-related differences across younger and older participants.

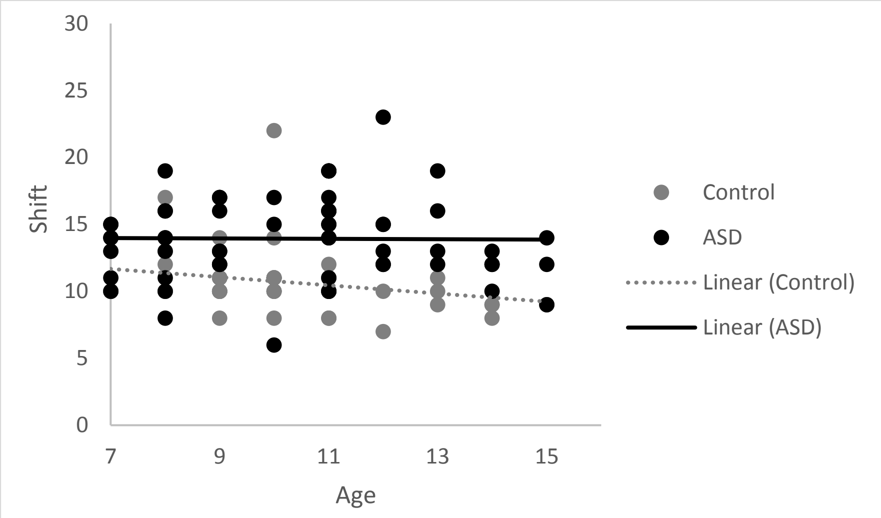



**Figure 6.2. Trajectory of "real-life" shift relative to age for controls and ASD participants**

**Brief_Emotion.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_emotion were significantly different between the two groups, $F$ (1, 119) = 11.91, $p$= .001, partial $\eta^2$=.09 at the lowest age of overlap. Regarding the rate of developmental change, neither chronological age [$F$ (1, 119) = 2.46, $p$=.12, partial $\eta^2$ = .02] nor the Group x Chronological Age interaction [$F$ (1, 119) = 1.12, $p$ = .29, partial $\eta^2$=.01] were found significant. Figure 6.3 show that there were non-significant age-related changes for either group.

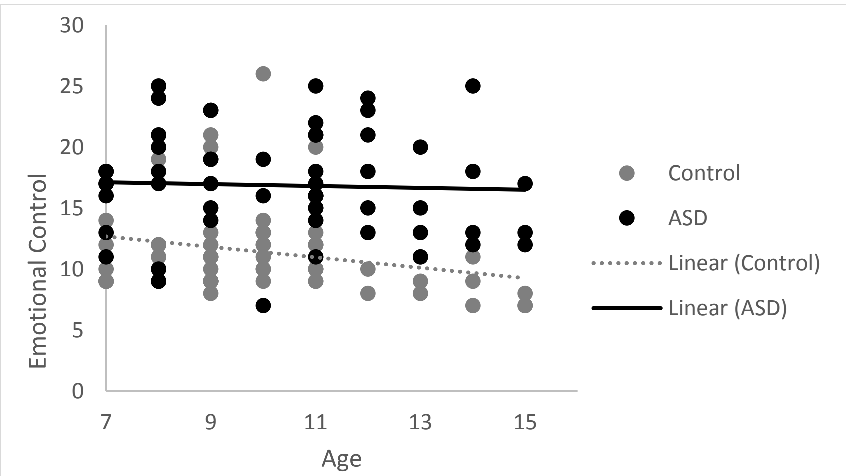



**Figure 6.3. Trajectory of "real-life" emotion control relative to age for controls and ASD participants**

**Brief_Initiate:** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_initiate were not significantly different between the two groups, $F$ (1, 119) = 3.64, $p$= .06, partial $\eta^2$=.03 at the lowest age of overlap. Regarding the rate of developmental change, chronological age [$F$ (1, 119) = .18, $p$=.67, partial $\eta^2$ = .002] was not a significant predictor overall but the Group x Chronological Age interaction [$F$ (1, 119) = 12.87, $p$ < .001, partial $\eta^2$=.1] was found significant. Figure 6.4 show that that for the control group, performance on brief_initiate improved, while for the ASD group it got worse with age.

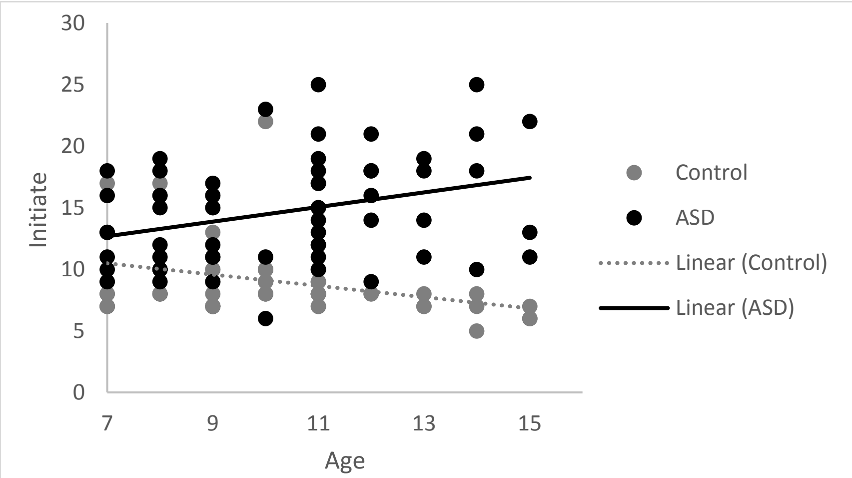



**Figure 6.4. Trajectory of "real-life" initiate relative to age for controls and ASD participants**

**Brief_Working Memory.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_working memory were significantly different between the two groups, $F$ (1, 119) = 8.59, $p$=.004, partial $\eta^2$=.07 at the lowest age of overlap. Regarding the rate of developmental change, chronological age was not a significant predictor of the brief_working memory scores, $F$ (1, 119) = .47, $p$=.45, partial $\eta^2$ = .04, but it was found that there was a significant Group x Chronological Age interaction, $F$ (1, 119) = 10.49, $p$= .002, partial $\eta^2$=.08. Figure 6.5 show that for the control group, brief_working memory scores presented age-related gains while for the ASD group there was a significant trend for brief_working memory to worsen with chronological age.

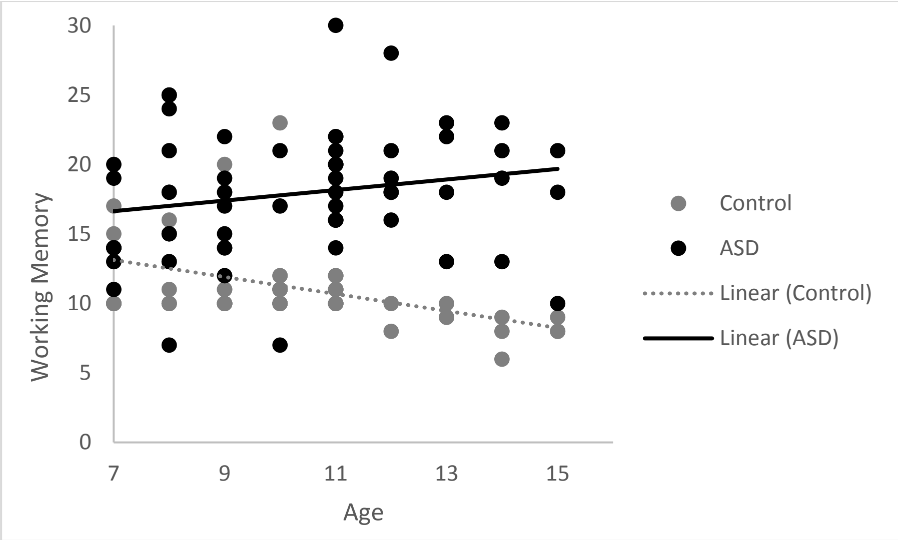



**Figure 6.5. Trajectory of "real-life" working memory relative to age for controls and ASD participants**

**Brief_Planning.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_planning were not significantly different between the two groups, $F$ (1, 119) = 3.35, $p$ = .07, partial $\eta^2$=.023 at the lowest age of overlap. Regarding the rate of developmental change, chronological age was not a significant predictor of the brief_planning scores, $F$ (1, 119) = 1.09, $p$=.29, partial $\eta^2$ = .01. However, it was found that there was a significant Group x Chronological Age interaction, $F$ (1, 119) = 10.05, $p$ = .002, partial $\eta^2$=.08. Figure 6.6 show that for the control group, brief_planning scores improved with age while for the ASD group there was a significant trend for brief_planning to worsen with chronological age.

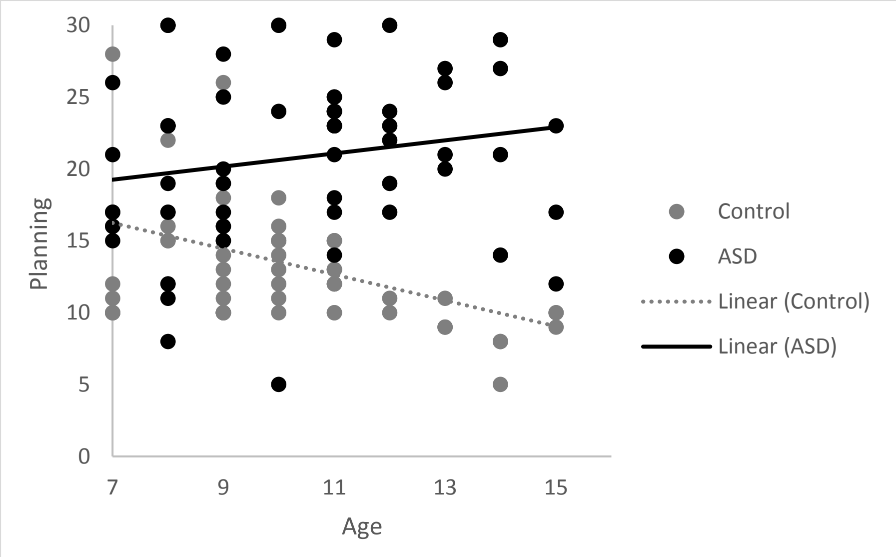



**Figure 6.6. Trajectory of "real-life" planning relative to age for controls and ASD participants**

**Brief_Organisation.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_organisation were significantly different between the two groups, $F$ (1, 119) = 9.03, $p$= .003, partial $\eta^2$=.07 at the lowest age of overlap. Regarding the rate of developmental change, chronological age [$F$ (1, 119) = .22, $p$=.64, partial $\eta^2$ = .002] was not a significant predictor overall but the Group x Chronological Age interaction [$F$ (1, 119) = 17.81, $p$ < .001, partial $\eta^2$=.13] was found significant. Figure 6.7 show that that for the control group, performance on brief_organisation improved, while for the ASD group it got worse with age.

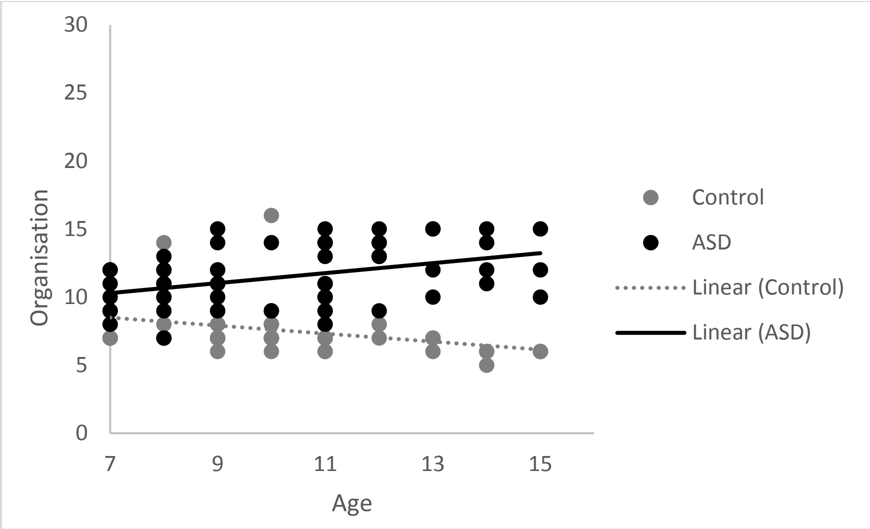



**Figure 6.7. Trajectory of "real-life" organisation relative to age for controls and ASD participants**

**Brief_Monitor:** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of brief_monitor were not significantly different between the two groups, $F$ (1, 119) = .41, $p$= .53, partial $\eta^2$=.03 at the lowest age of overlap. Regarding the rate of developmental change, chronological age [$F$ (1, 119) = .07, $p$=.79, partial $\eta^2$ = .001] was not a significant predictor overall but the Group x Chronological Age interaction [$F$ (1, 119) = 19.97, $p$ < .001, partial $\eta^2$=.15] was found significant. Figure 6.8 show that that for the control group, performance on brief_monitor got better, while for the ASD group it got worse with age.

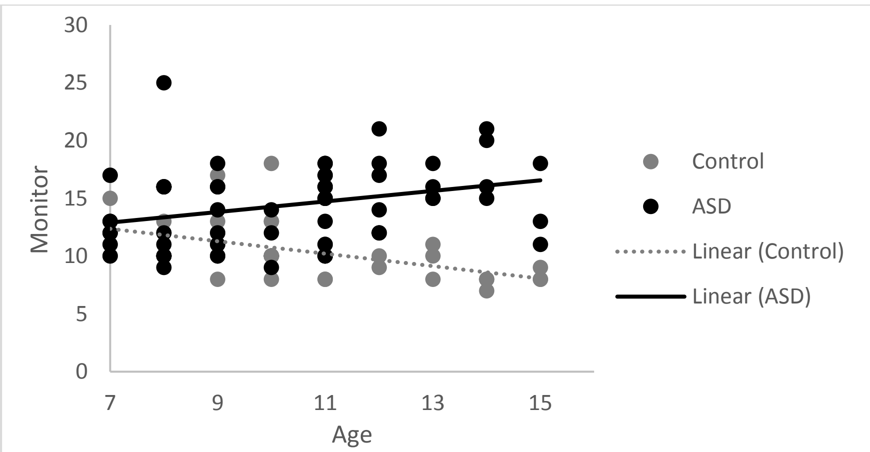



**Figure 6.8. Trajectory of "real-life" monitor relative to age for controls and ASD participants**

### 6.3.3. Cross-sectional developmental trajectories of adaptive skills relative to age

**Communication.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of communication were significantly different between the two groups, $F$ (1, 119) = 34.41, $p$< .001, partial $\eta^2$=.23 at the lowest age of overlap. Regarding the rate of developmental change, chronological age [$F$ (1, 119) = 9.96, $p$ = .002, partial $\eta^2$ = .08] was a significant predictor overall but the Group x Chronological Age interaction [$F$ (1, 117) = .21, $p$ = .65, partial $\eta^2$=.002] was not found significant. Figure 6.9 show that for both groups performance on communication got worse with age.

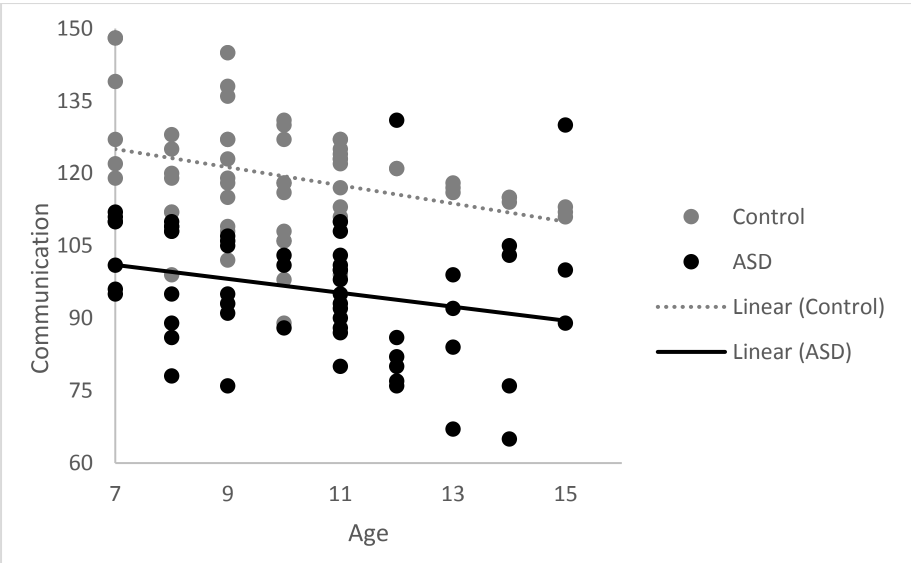



**Figure 6.9. Trajectory of adaptive communication relative to age for controls and ASD participants**

**Daily Living.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of daily living were significantly different between the two groups, $F$ (1, 119) = 50.52, $p$< .001, partial $\eta^2$=.31 at the lowest age of overlap. Regarding the rate of developmental change, neither chronological age [$F$ (1, 1179) = .002, $p$ =.96, partial $\eta^2$ = .003] nor the Group x Chronological Age interaction [$F$ (1, 119) = .53, $p$ = .47, partial $\eta^2$= .005] were found significant. Figure 6.10 show that that performance on daily living presented non-significant age-related changes for either group.

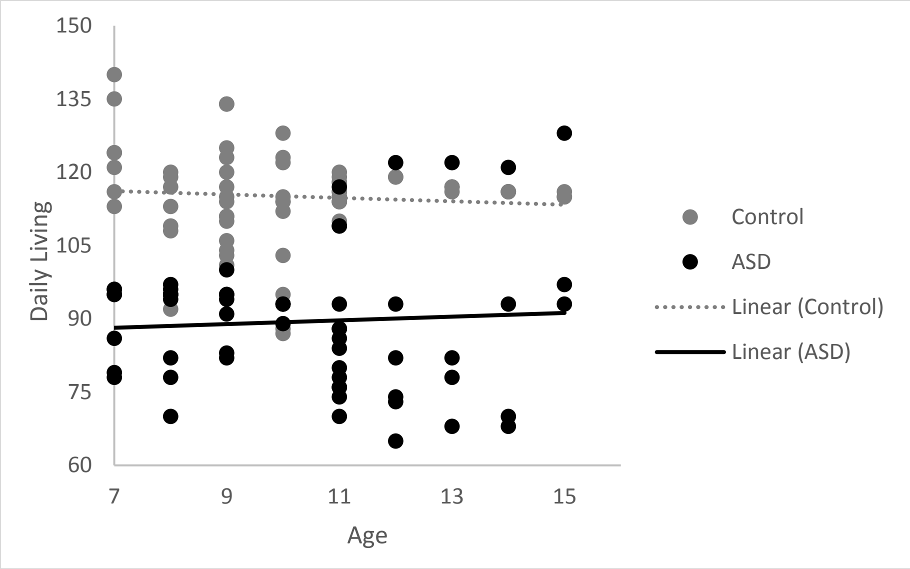



**Figure 6.10. Trajectory of adaptive daily living relative to age for controls and ASD participants**

**Socialisation.** The intercept of the trajectory was evaluated at the lowest age of overlap between the two groups (i.e. 7 years of age) and the within-group trajectory slopes. The intercepts of socialisation were significantly different between the two groups, $F$ (1, 119) = 42.88, $p$ < .001, partial $\eta^2$=.027 at the lowest age of overlap. Regarding the rate of developmental change, neither chronological age [$F$ (1, 117) = .77, $p$ = .38, partial $\eta^2$ = .007] nor the Group x Chronological Age interaction [$F$ (1, 117) = 1.88, $p$ = .17, partial $\eta^2$= .016] were found significant. Figure 6.11 show that that performance on socialisation presented non-significant age-related changes for either group.

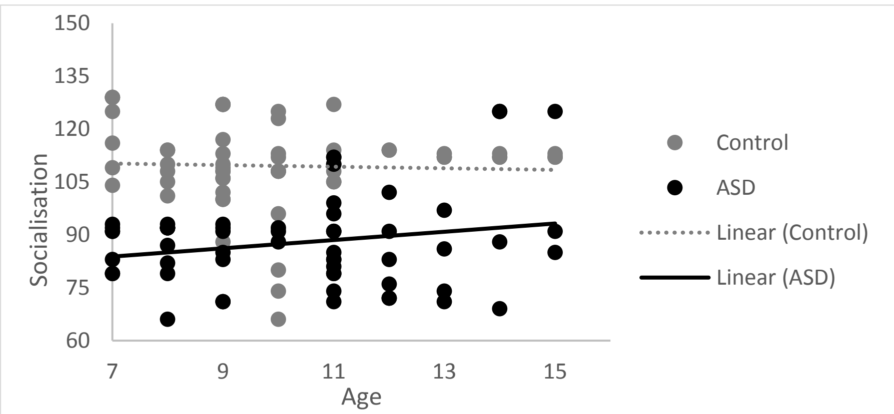



**Figure 6.11. Trajectory of adaptive socialisation relative to age for controls and ASD participants**

### 6.3.4. Associations between the cross-sectional developmental trajectories of adaptive skills, "real-life" EF and performance-based EF

Table 6.2 shows that adaptive skills (communication, daily living, and socialisation) were correlated with all "real-life" EF aspects. However, the performance-based EF aspects were correlated only with selective adaptive skills. Delay discounting was not associated with any of the three adaptive skills. Performance-based cool EF measures from Study Three: digit span (working memory), ToL (planning), and Go/No-Go (inhibition) were found weakly to non-significantly associated with the equivalent cool EF domains of BRIEF. Hot EF measures presented no significant associations with any of the BRIEF domains.

**Table 6.2. Correlations between performance-based EF, "real-life" EF and adaptive skills**

| | Communication | Daily Living | Socialisation |
|---|---|---|---|
| Brief_Inhibition | -.59** | -.54** | -.49** |
| Brief_Shift | -.56** | -.59** | -.55** |
| Brief_Emotion Control | -.61** | -.65** | -.58** |
| Brief_Initiate | -.69** | -.64** | -.59** |
| Brief_Working Memory | -.64** | -.64** | -.61** |
| Brief_Planning | -.61** | -.59** | -.54** |
| Brief_Organisation | -.63** | -.69** | -.57** |
| Brief_Monitor | -.59** | -.55** | -.47** |
| Digit Span | .43** | .35** | .32** |
| ToL | .22* | .23* | .16 |
| Go/No-Go | -.18 | -.34** | -.29** |
| IOWA | .32** | .28** | .33** |
| Delay Discounting | -.14 | -.11 | -.14 |

| | Digit Span (performance-based) | ToL (performance-based) | Go/No-Go (performance-based) |
|---|---|---|---|
| Brief_Working Memory | -.14* | -.21* | .17 |
| Brief_Planning | -.18* | -.19* | .18 |
| Brief_Inhibition | -.13 | -.22 | .09 |

*p<.05, **p<. .01

The relation between performance-based, "real-life" EF and adaptive skills was further investigated by running three hierarchical multiple regression analyses to examine which of the two different sets of EF (*performance-based* & *"real-life"*) significantly predicted adaptive skills independent of ASD diagnosis and over and above control variables (age & FSIQ). Delay discounting was not included in the regression models as it was not related to any of the EF aspects. Dependent variables were *communication, daily living, and socialisation.*

Full results of the hierarchical regression analysis are presented in Table 6.3. These show that the first block introducing age, IQ, and ASD contributed significantly to the variance of communication, $F$ (3, 109) = 52. 43, $p$ < .001, explaining 59.1% of the variance. For EF aspects entered in block 2, the total variance explained rose to 72.3%, representing a significant increase of 13.2% [$F$ (12, 97) = 3.86, $p$ <.001] additional variance explained. Communication scores were significantly predicted by "real-life" emotion control ($p$ = .007) and "real-life" initiate ($p$ = .045) overall in participants with and without ASD.

Regarding daily living, control variables and ASD explained 58.8% of the variance in daily living scores [$F$ (3, 109) = 51.92, $p$ < .001]. For EF variables entered in block 2, the total variance explained rose to 71.1%, representing a significant increase of 12.3% [$F$ (12, 97) = 3.45, $p$ <.001] additional variance explained. Daily Living scores were significantly predicted by "real-life" emotion control ($p$ = .014) in participants with and without ASD.

In terms of socialisation, control variables and ASD explained 47% of the variance in socialisation scores [$F$ (3, 109) = 31.59, $p$ < .001]. For EF variables entered in block 2, the total variance explained rose to 59.1%, representing a significant increase of 12.52% [$F$ (12, 97) = 2.48, $p$ =.008] additional variance explained. However none of the individual EF predictors was found significant.

Adaptive skills were predicted only by "real-life" but not performance-based EF aspects in children and adolescents with and without ASD.

**Table 6.3. Hierarchical regression analysis for adaptive skills scores by group and EF variables**

| Predictors | Communication | | Daily Living | | Socialisation | |
|---|---|---|---|---|---|---|
| | β | $\Delta R^2$ | β | $\Delta R^2$ | β | $\Delta R^2$ |
| *Step 1* | | .59** | | .59** | | .47** |
| Control variables | | | | | | |
| Age | -.05 | | .13 | | .15 | |
| IQ | .37** | | .27** | | .19* | |
| ASD diagnosis | -.59** | | -.69** | | -.64** | |
| *Step 2* | | .13** | | .12** | | .13** |
| EF | | | | | | |
| Digit Span | .02 | | -.03 | | .04 | |
| ToL | -.01 | | .04 | | -.03 | |
| Go/No-Go | .001 | | -.09 | | -.08 | |
| IGT | .12 | | .09 | | .19 | |
| Brief_Inhibition | -.21 | | -.08 | | -.09 | |
| Brief_Shift | .66 | | -.08 | | -.18 | |
| Brief_Emotion | .47** | | -.35** | | -.26 | |
| Brief_Initiate | .44* | | -.09 | | -.27 | |
| Brief_WM | .46 | | .05 | | -.01 | |
| Brief_Planning | .46 | | .31 | | .32 | |
| Brief_Organisation | .64 | | -.17 | | .07 | |
| Brief_Monitor | .49 | | -.01 | | .11 | |
| $R^2$ | | .72** | | .71** | | .6** |
| *F* test | | 3.87 | | 3.21 | | 2.49 |

Note. *p <. 05, **p < .01.

### 6.4. Discussion

The present study employed the cross-sectional developmental trajectory approach, also used in Study Three (Chapter 5) , in order to investigate the developmental patterns of "real-life" EF of children and adolescents with ASD relative to typically developing peers, as reported by their teachers. Moreover, the predictive relation between "real-life", performance-based EF measures and adaptive skills was examined. Age-related declines were found in several "real-life" EF domains (inhibition, initiate, working memory, planning, organisation, self-monitor) but not for EF emotional control and shift that presented non-significant changes with age. These results suggest that several "real-life" EF problems become more evident in adolescence, after the transition from primary to secondary education. It seems that the "real-life" EF developmental patterns in ASD deviate from those of typical development. Moreover, the patterns of development found for selective BRIEF EF aspects (inhibition and planning) were different compared to the relevant performance-based EF profiles presented in Study Three and also weakly or non-significantly related. Finally, it was found that only "real-life" and not performance-based EF predicted adaptive skills over and above age and IQ in children and adolescents with and without ASD.

#### 6.4.1. Developmental Profiles of "real-life" EF

For the three EF aspects of the Behavioural Regulation Index (BRI; inhibition, shift, and emotional control), results showed that inhibition presented age-related declines while performance on emotion control and shift was not altered across age in the ASD group. The developmental declines in inhibition scores in the ASD group contradict previous studies (using the BRIEF) that showed either developmental gains (van den Bergh et al., 2014) or lack of improvements (Rosenthal et al., 2013) across younger and older participants in ASD. One possible explanation for such discrepancies could be the significant IQ superiority of the older ASD participants in those studies compared to the present study (difference more than 10 points in mean IQ performance). Such lower levels of general cognitive ability may have accounted for the report of increasing inhibition problems in adolescents with ASD in the present study, as the latter may not effectively deal with the more advanced cognitive inhibitory loads of secondary education. With respect to shift, the lack of age-related changes in present study is in line with both Rosenthal et al. (2013) and van den Bergh et al.'s (2014) studies and suggests that if shift problems are among the core deficits for ASD as proposed (Craig et al., 2016), there is at least a non-significant pattern of increasing problems across childhood and adolescence. Finally, the lack of age-related differences in the third domain of the BRI Index, emotion control, shows that reported problems in the ability to modulate emotions are stable across childhood and adolescence in ASD.

In terms of the "real-life" EF domains of the Metacognition Index (planning, working memory, initiate, organisation, and self-monitoring), results showed that all domains presented age-related declines. The significant age-related performance declines in working memory are in line with Rosenthal et al. (2013) that found that adolescents with ASD showed increased parent-report problems in working memory. It could be assumed that the developmental pattern of "real-life" working memory in children and adolescents with ASD differs from the typical one and may present an increase in deficits with age. Declines in planning performance in ASD are in line with van den Bergh's study showing that adolescents (12-14 years) had more planning problems compared to younger children (9-11 years). Age declines in all metacognitive domains suggest that children with ASD are more vulnerable to changes in the demands of their environment with their EF problems increasing during adolescence relative to typically developing peers that mainly present developmental gains. This could be explained in the basis of the more advanced demands of the school environment for children entering adolescence. Adolescents with ASD are expected to start handling their school workload more independently and present enhanced abilities of initiation, organisation/planning or monitoring of everyday tasks relative to younger children which may subsequently lead to increased expectations from their environment.

### 6.4.2. Comparison with performance based EF developmental profiles

Discussion of the comparison between "real-life" and performance-based EF will be only made at the level of working memory, planning and inhibition as these are the only "real-life" aspects that were also addressed-through lab measures- in children and adolescents with ASD in Study Three. Results from Study Three showed that after employing the cross-sectional developmental trajectory approach to the same ASD participants as in the present chapter, working memory presented age-related declines, inhibition age-related improvements, and planning non-significant developmental gains across younger and older participants with ASD. In terms of working memory, both measures' cross-sectional trajectories seem to be similar, proposing that working memory deficits emerge more dramatically after middle childhood and persist during adolescence. However, planning and inhibition seem to present quite dissimilar developmental patterns across the two kind of EF measures, raising questions about their underlying maturational processes. There is a growing body of evidence recently suggesting that "real-life" EF ratings and performance-based EF measures may in fact assess different underlying mental constructs. Performance-based tasks are suggested to provide an indication of processing efficiency (i.e. the algorithmic level of cognitive analysis) while rating measures may reflect the individual goal pursuit (i.e. the reflective level of cognitive analysis) (Toplak et al., 2013). Stanovich (2011) proposes that individual differences at the algorithmic level reflect the efficiency of the functional cognitive machinery (regulated by the prefrontal cortex) that carries out mental tasks, whereas individual differences at the reflective control (potentially regulated by specific areas of the orbitofrontal cortex, which have direct connections to amygdala; Campbell, 2015) may derive from variance in higher-level goal states and epistemic thinking dispositions of examinees. Starting from an operationalisation perspective, performance-based and rating measures of EF differ in the basis of administration and scoring. Performance-based measures are administered in standardised conditions while presentation is carefully controlled in order for each participant to experience the task the same way. Performance is also assessed not only at the level of accuracy, but also response time or speeding responding under a specific time frame. The rating scales of EF on the other hand capture either the teachers' or parents/ caregivers' report of the level of competence of examinees in complex, every day, problem-solving situations (Roth et al., 2005). It could be thus assumed that rating scales measure mainly behaviours (i.e. goal pursuit) that are related to the EF processes assessed by performance based EF, rather than the EF processes (i.e. efficiency in cognitive abilities) per se. Moreover, evidence from a recent meta-analysis (Toplak et al., 2013) of previous studies having investigated the interrelation between these two types showed that the association between ratings on the BRIEF and performance-based measures was really weak. This pattern of weak to non-significant correlations was also evident in the present study as shown in table 6.2. Toplak et al. (2013, p.137) conclude that despite both types of measures are meant to capture the same underlying cognitive construct, "a basic principle of convergent validity in science is that different operational measures of the same construct should correlate highly". It could be thus argued that performance-based and ratings of EF may measure different cognitive skills which however separately contribute to clinical phenotypes (i.e. ASD). The most important implication is that, as there is evidence of performance-based and rating scales indexing different level of cognitive analysis, they should not be used interchangeably as parallel measures of EF but only in combination, especially in clinical research.

### 6.4.3. Developmental profiles of Adaptive skills and associations with EF

The present study sought to investigate the relationship between the cross-sectional trajectories of both types of EF measures and adaptive skills in children and adolescents with ASD. Results showed that only communication presented age-related declines while daily living and socialisation demonstrated no significant developmental differences across age in ASD. This pattern of findings with declines and/or stability of deficits over age is in line with previous evidence suggesting there are points in the development of adaptive skills in ASD in which growth may plateau or decline with age (Fisch et al., 2002; Pugliese et al., 2015). The performance losses in adaptive skills in adolescence in ASD is not surprising considering the robust significant relationship adaptive behaviour shares with deficits in EF. Results showed that selective "real-life" EF indices contributed to adaptive behaviour (only communication and daily living scores) over and above age, IQ and ASD diagnosis. It should be noted at this point that only "real-life" but not performance-based EF measures predicted communication and daily living in participants with and without ASD. This pattern of findings (weak correlations, different developmental trends and prediction of different outcomes) supports the theoretical account (Toplak et al., 2013) presented above proposing that "real-life" EF may detect executive problems relative to performance-based EF aspects that detect skills.

Breaking down further into specific "real-life" EF domains, it was found that adaptive communication was predicted by emotion control and initiate in participants with and without ASD. Emotion control (or alternatively emotion regulation as cited in other studies) has been widely emphasised in ASD as it may aid in understanding the emotional and behavioural problems observed in several ASD samples. Emotion control is suggested to play an important role in social relations and communicative setting in general (Gross, Richards, & John, 2006), as the ability to modulate and inhibit one's emotions enables them to take other people's perspectives and feelings into consideration. The association between adaptive communication and initiation is more difficult to comment on as there has been limited attention in this area of EF in ASD. This may be partially explained due to the objective difficulty of assessing the ability of initiating an activity ("self-starting") within a structured lab setting. As BRIEF items measure mainly aspects of generativity in problem solving, the predictive relation between initiation and communication could be related to the general social deficits of ASD (i.e. difficulty in initiating, terminating, or facilitating a conversation). Adaptive daily living (mainly academic and school community skills) was predicted only by emotion control in both groups highlighting again the importance of such ability in children's social and academic success. Robust emotion control is thought to be related to school and academic success through behavioural control within the classroom (Graziano et al., 2007). The present findings suggest that emotion control skills relate to children's learning and productivity in the classroom. Finally, the lack of significant predictive relations between EF and the third adaptive skill, socialisation, could be attributed to the sample size as "real-life" EF initiate was marginally a significant predictor (*p*= .064), which suggests there might have been a lack of statistical power.

Building on Study Three, the present study employed the same cross-sectional developmental trajectory approach to explore the developmental trajectories of "real-life" EF (as reported by teachers) of children and adolescents with ASD compared to controls. This study expanded on previous findings by comparing the developmental trajectories of the performance-based EF of Study Three with "real-life" EF ratings. Results showed that several "real-life" EF problems increase in adolescence and the pattern of development for some "real-life" EF aspects (inhibition and planning) were different compared to the performance-based EF profiles of those aspects presented in Study Three. This data provided support to the hypothesis that "real-life" EF may actually tap different cognitive constructs. Such differentiated developmental trajectories along with the weak/non-significant correlations, and the fact that they do not predict the same developmental outcomes (e.g. only "real-life" EF predicted adaptive skills) highlight the distinct nature of performance-based and rating scales of EF. In conclusion, the present study showed that EF is a complex, non-unitary construct tapping several multiple and distinct cognitive processes and behaviours. Shedding more light on the developmental course of all types of EF processes as well as their association with crucial social outcomes in ASD could contribute to a better theoretical understanding of the heterogeneity of the neurocognitive development in ASD.

# CHAPTER VII

# GENERAL DISCUSSION

## 7.1. Chapter overview

The present chapter will discuss the findings from Studies One to Four (Chapters 3-6). Firstly, a summary of the main findings of each study will be provided, followed by their association with the research questions stated at the end of Chapter 1. The contribution of the four studies to the wider literature, limitations and final conclusions will be then presented. Finally, the implications drawn from studies will be identified, along with potential paths for future research.

## 7.2. Summary of findings

The primary goal of the research covered in the present thesis was the examination of the development of EF at the level of hot and cool aspects and "real-life" EF ratings, across age and time (follow-up after one year) as well as their associations to ToM and adaptive skills in children and adolescents with ASD. This was the first piece of research to take the role of both hot and cool EF into account when investigating developmental trends of such cognitive abilities in children and adolescents with ASD and was the first one to assess the links between both EF systems to ToM longitudinally across middle childhood in ASD. The cross-sectional developmental patterns of "real-life" EF domains and the direct comparison with the development of performance-based EF were also examined for the first time in ASD. For that reason, four studies were conducted based on data from a sample of 170 children and adolescents between 7 and 16 years old with and without ASD. A subsample of these participants was followed up one year after the initial assessment (assessed at two time points: initial recruitment (Time 1), and 12 months later (Time 2). These four studies aimed to clarify the nature of the developmental pathway followed in ASD relative to neurotypicals and aid in our better understanding of the neurocognitive impairments in EF that underpin crucial social and behavioural outcomes in middle childhood and adolescence in ASD. The findings of Studies One to Four are summarised and integrated below:

The first study (Chapter 3) was the first cross-sectional study to date to assess EF profiles of school-aged (middle childhood) children with ASD relative to typically developing peers (7-12 years) employing both cool and hot EF tasks. It also examined the concurrent associations between both hot and cool EF processes and ToM mechanisms in school-aged children with and without ASD. Results showed that participants with ASD were characterised by a general executive dysfunction as they presented significantly lower performance in each cool and hot EF task. Findings also provided support to the well-established correlation between cool EF and ToM and further revealed a significant predictive association between hot EF (delay discounting) and ToM mental state/ emotion recognition. This is the first study to date to report not only that school-aged children with ASD exhibit hot EF impairment, which may contribute to their deficits in ToM, but also that a hot EF aspect significantly predicts ToM mechanisms (mental state/ emotion recognition ability) over and above cool EF in middle childhood in ASD. As only one of the hot EF aspects predicted only one of the ToM aspects over and above cool EF, Study One provided partial support to the hypothesis that hot EF may be more associated with ToM (e.g., mental state/emotion recognition) than cool EF (Zelazo et al., 2005). Study One served as the first step towards the better theoretical understanding of the role of separate cool and hot EF systems play in the ToM mechanisms in ASD and typical development cross-sectionally.

Study Two (Chapter 4) expanded the evidence of the concurrent associations found between hot and cool EF and ToM as it focused on the longitudinal links between both cognitive domains across school age (middle childhood) in ASD and typical development. Although it is generally accepted that EF provides a platform for the emergence of ToM in early childhood in ASD and typical development, there is limited knowledge about their links in middle childhood (school age; 7-12 years) and whether hot EF can also influence ToM later performance. It also examined the developmental changes of hot, cool EF and ToM abilities of children with ASD relative to typically developing peers across time (second time point after a year). The developmental framework of EF and ToM is quite unclear in ASD to date due to mixed results (some studies report age-related gains, some other constant deficits across development). Moreover, there has been no consensus yet on the nature of the developmental trajectory of EF in ASD relative to controls (is it delayed, deviant or both?). Study Two (Chapter 4) provided the first investigation of the longitudinal associations between cool and hot EF and ToM, in children 7- to 12-years-old with and without ASD. This longitudinal study revealed that in the ASD group, only cool working memory, cool inhibition, and hot affective decision making presented significant age-related gains after one year but their impairments, present from the initial assessment, remained throughout development without reaching the levels of neurotypicals. Cool EF planning performance of ASD participants was similar to that of controls with both groups showing developmental gains across one year. For "hot" delay discounting results indicated non-significant developmental differences after a year in either group. The pattern of development for EF seems to be quite mixed, and rather inconsistent within each separate EF domain, across time in ASD. Furthermore, regarding the ToM abilities, although mental state/ emotion recognition presented age-related improvements, its developmental pattern was rather deviant to controls as children's deficits remained present across time in ASD. For false belief, development followed a delayed pattern in ASD as their performance reached the level of the controls at the second assessment point (after one year). Study Two provided a better insight into the developmental pathway of cool and hot EF followed in ASD across school age, highlighting the importance of investigating the underlying maturation processes of cognitive skills in ASD which seem to be intact for several EF subcomponents in middle childhood. With regards to the longitudinal associations between cool and hot EF and ToM abilities in children with and without ASD across school age, it was found that early cool working memory and hot delay discounting predicted later ToM abilities adding support to the well documented theoretical account of early EF predicting later ToM, and not the other way round. More specifically, cool EF working memory predicted later ToM false belief overall in children with and without ASD, while hot delay discounting predicted later ToM mental state/ emotion recognition over and above cool EF and control variables only in the ASD participants. The extension of this significant link of ToM to hot delay discounting as well indicates the importance of considering both hot and cool EF aspects in cognitive research in ASD. No evidence was found to support the argument that ToM abilities predict later EF. Study Two was the first study to date to report that an early hot EF aspect (delay discounting) predicted later ToM above and beyond cool EF in school age in ASD. Overall Study Two made a significant contribution to background literature shedding more light on the multidimensional nature of EF and its role as risk factor for other poor developmental outcomes (i.e. ToM).

Studies One and Two therefore provided preliminary evidence for the important role of hot EF in the cognitive and developmental profile of school-aged children with ASD, highlighting the need to further study the underlying maturation processes of such neurocognitive and social deficits in ASD across middle and later childhood as it may increase our theoretical understanding of the higher-order cognitive deficits underpinning the ASD phenotype. While Studies One and Two examined the role of cool and hot EF skills and ToM in school age (middle childhood) both cross-sectionally and longitudinally, Studies Three (Chapter 5) and Four (Chapter 6) examined the cross-sectional developmental trajectories among these cognitive abilities as well as other social outcomes too (adaptive skills) across a broader age range; expanding from middle childhood to adolescence too (7-16 years).

Study Three (Chapter 5) was the first study to date to assess the cross-sectional developmental trajectories of hot and cool EF and ToM in children and adolescents with and without ASD. After identifying the developmental course and longitudinal associations between EF and ToM in school-aged children between 7-12 years, it is important to investigate the development of cool and hot EF and their interconnection with ToM from childhood to adolescence as well, considering the fact that the cognitive skills in ASD are thought to emerge within a dynamic developing system (Pellicano, 2012) with EF providing a platform for the ToM developmental trajectory until early adulthood. Also, the development of hot EF in childhood and adolescence is relatively understudied. Given that the underlying brain regions may be subject to change and become more specialised with age it is also important to study the internal organisation of hot and cool EF from childhood to adolescence. Study Three (Chapter 5) focused on comparing the cross-sectional developmental EF and ToM trajectories of ASD participants relative to typically developing peers (7-16 years), in order to assess the contributions of chronological age on each group's development. Additionally, the contribution of IQ on the EF and ToM developmental trajectories was also investigated since IQ is widely considered in the literature to be related to the development of EF in ASD (Ardila et al., 2000; Arffa, 2007). The cross-sectional developmental trajectories approach, in contrast to traditional group means comparison, can reveal important information about delayed onsets and slower rates of development between the trajectories. Only cool working memory and inhibition demonstrated age-related differences, while planning presented lack of improvements in ASD. The hot EF trajectories showed no significant improvements across childhood and adolescence in ASD. With regards to IQ, only cool working memory and planning abilities presented changes between lower and higher FSIQ functioning participants in ASD. No IQ-related differences were found for hot EF aspects. For ToM, improvements with age were found in both false belief and mental state/ emotion recognition. However, in terms of IQ, only ToM mental state/ emotion recognition showed improvements with higher IQ scores in ASD while false belief presented no improvements across IQ. Finally, hot and cool EF measures were not significantly associated in the ASD group (only in the control), while hot EF predicted ToM mental state/ emotion recognition over and above cool EF in participants with and without

ASD. In contrast to the specific developmental EF improvements of Study Two, Study Three showed that most EF skills no longer presented significant performance gains in adolescence in ASD. Hot EF delay discounting however still shared a significant developmental association with ToM trajectory beyond middle childhood in both groups.

Building on Study Three, Study Four (Chapter 6) employed the same cross-sectional developmental trajectory approach as in Study Three in order to identify the developmental pattern of “real-life” EF (as reported by teachers) of the same (as Study Three) children and adolescents with ASD relative to typically developing peers. This study expanded on previous research by comparing for the first time the developmental pathways of the two different types of EF measures (“real-life” ratings and performance-based tasks) along with examining the predictive relation between both types and adaptive skills in children and adolescents with ASD. Age-related losses in performance were found in several “real-life” EF domains (inhibition, initiate, working memory, planning, organisation, self-monitor) but not for EF emotional control and shift that showed non-significant alterations across age. These results suggest that several “real-life” EF problems may increase in adolescence, after the transition from primary to secondary education. Similarly to Study Three, it seems that the “real-life” EF cross-sectional developmental trajectories also deviate from those of typical development. Besides this, it was also found that the pattern of development found for some “real-life” EF aspects (inhibition and planning) were different compared to the performance-based EF profiles of those aspects presented in Study Three providing support to the hypothesis that “real-life” EF may actually tap different cognitive constructs. Finally, it was found that only “real-life” and not performance-based EF predicted adaptive skills over and above age and IQ in children and adolescents with and without ASD. Such differentiated developmental trajectories, the weak/non-significant correlations, and the rise they give to different developmental outcomes, indicate the distinct nature of performance-based and rating scales of EF and highlight once again the heterogeneity of the neurocognitive impairments in ASD.

## 7.3. Relations of findings to the Research Questions

In the following section, findings from Studies One to Four will be linked to the research questions stated at the end of Chapter One. Discussion will be brief here as the importance of the findings answering these questions and their application to the wider literature will be analysed in greater detail in the next section.

**Research Question 1:** ***What is the association between hot and cool EF and ToM in ASD and typical development in middle childhood? Are the early hot and cool EF predictors of later ToM (after a 1 year interval) or vice versa in ASD? Is there a link between both hot and cool EF and ToM in ASD across middle childhood (7-12 years)?***

Results from Studies One and Two confirmed that EF and ToM are indeed strongly associated in middle childhood and showed that these relationships are specific. Results showed that both cool and hot EF skills were linked to ToM mental state/ emotion recognition and false belief knowledge in children with and without ASD in middle childhood. These findings support the vast majority of previous studies (see for a review Devine & Hughes, 2014) stating that only early EF predicted later ToM rather while no evidence was found for the reverse pattern; early ToM predicting later EF. The present thesis added more to the theoretical account which suggests that emerging EF provides a platform for the development of ToM both in typical development (Flynn, 2007; Hughes, 1998b) and ASD (Pellicano, 2010). According to this account, early EF skills predict later ToM; thus children would first need to obtain sufficient EF skills and then understand and process ToM false beliefs or mental states (Russell, 1996) as shown by the present study too. Results from Study Two showed that after controlling for concurrent age, FSIQ, and prior ToM, early working memory predicted later ToM false belief in ASD and typical development while early delay discounting predicted later ToM mental state/emotion recognition in ASD. The present thesis does not support Perner's (1998) proposition that the acquisition of ToM is a prerequisite of children's EF by suggesting that longitudinal contributions from earlier EF are needed towards the successful completion of a ToM task. This will be discussed further in the next section.

**Research Question 2:** ***What are the cross-sectional developmental trajectories of performance-based cool and hot EF and ToM on a larger age group of not only children but adolescents with ASD as well, compared to typically developing peers? Is there any association between the trajectories of hot and cool EF and ToM, expanding such investigation beyond middle childhood (7-16 years) in both groups?***

Study Three was the first study to date to look at the developmental EF patterns of typical development and ASD by employing the cross-sectional developmental trajectories approach which, unlike the traditional comparisons of group means, identifies delayed onsets or deviant rates of development across childhood and adolescence. Results showed that cool EF cross-sectional developmental trajectories presented differences, compared with the typically developing peers. More specifically, working memory presented age-related declines from younger to older participants in ASD while the performance of controls became better with age. For planning, participants with ASD presented non-significant developmental differences relative to controls for whom performance improved. Finally, inhibition was the only cool EF aspect that was found to improve significantly across age in ASD, in line with typical development, but performance never reached that of the controls. Generally, the present thesis provided mixed evidence regarding the cool EF developmental trajectories of children and adolescents with ASD as each skill presented a differentiated pattern which highlights the heterogeneity of EF neurocognitive deficits across development in ASD. Taking this evidence together (i.e. declines in working memory, no improvements in planning but improvements in inhibition without ever reaching the controls' performance though), it could be argued that these findings are partially in line with previous evidence (Ozonoff et al. 2004) suggesting that deficits may persist or even increase across the developmental transition from primary to secondary settings where demands of the environment are higher. In terms of hot EF, both affective decision making and delay discounting were shown to present non-significant developmental changes, similar to controls. The present thesis was the first study to examine the development of hot EF in ASD from childhood to adolescence. Results showed that hot EF demonstrated non-significant age-related changes in both typical development and ASD, contrary to cool EF aspects such as inhibition or working memory. The lack of change in both groups' performance in hot EF from childhood to adolescence was quite surprising contradicting developmental theoretical accounts (Segalowitz & Davies, 2004) positing that the hot EF developmental pathway would be protracted across childhood and early adolescence, following the extended development of the ventromedial prefrontal cortex. Conclusions from the direct comparisons with previous studies (Hooper et al., 2004; Scheres et al., 2006) that reported age-related improvements in hot aspects such as delay discounting cannot be drawn due to different constructs tapped by each different hot EF measure. For example the different designs (temporal or probabilistic) with different magnitudes of the immediate monetary reward or different delays that were employed in the aforementioned studies may indeed follow developmental gains across childhood and adolescence. Moreover, the failure to address real monetary awards in both hot EF tasks may have also accounted for the lack of motivation of older participants (adolescents) in the present thesis to choose larger rewards during the delay task or demonstrate reduced risk taking in Iowa gambling task.

The present thesis shed more light on the extension of the EF-ToM relationship beyond early childhood and suggested that both constructs are still strongly associated throughout development. This developmental association was further expanded as well, showing that not only cool but hot EF trajectories as well contribute to ToM explaining of variance in children and adolescents with and without ASD. Cool EF and ToM share a strong, well established relationship independent of control variables, especially in typical development, as corroborated by the present findings. ToM mental state/ emotion recognition was predicted by cool EF (inhibition and planning) suggesting that participants with and without ASD who performed better in the Go/No Go and ToL tasks for example could more easily disengage from their own mental/ emotional states or suppress irrelevant ones, and subsequently plan how to infer advanced empathising skills for another's emotion. Most importantly, hot delay discounting also predicted ToM mental state/ emotion recognition over and above cool EF and control variables in typical development and ASD. Participants who were less impulsive and chose larger delayed rewards demonstrated higher scores in the Eyes task (emotion recognition). Generally, it is suggested that emotional functioning may relate to the development of temporal perspectives (Stolarski et al., 2011). The present thesis suggested that the development of a balanced temporal perspective seems to associate somehow with the development of emotion recognition and regulation in ASD and typical development. There is robust evidence connecting ToM and EF skills (Austin et al., 2014; Carlson and Moses, 2001; Flynn et al., 2004) across several developmental stages with several reasons having been put forward for this persisting relationship. EF and ToM have been found to follow rapid developments during the preschool years but present findings suggested they may share a common neurological basis (prefrontal cortex) (Calderon et al., 2010; Austin et al., 2014). Both constructs remained intertwined in the course of development.

**Research Question 3:** ***What are the developmental trends of performance-based cool and hot EF in ASD compared to typically developing peers in middle childhood and adolescence? Is there a developmental delay or deviance in ASD trajectories relative to controls?***

Looking at the investigation of the developmental trends of EF in ASD longitudinally (after a year) only in school age (middle childhood), results showed that school-aged (7-12 years) children with ASD presented age-related improvements in all cool EF but selective hot EF aspects. Age-related improvements in cool EF after a year imply that during middle childhood the cool EF aspects of working memory, inhibition, planning present developmental gains in ASD, supporting previous reports of EF improvements during childhood both in typical development (Carlson et al., 2013; Gur et al., 2012) and in ASD (Pellicano, 2010). It is crucial to note though that despite the reported developmental changes in cool working memory and inhibition, children with ASD presented impairments in these aspects relative to matched neurotypicals which remained present across development and never reached the performance level of the control group. This pattern of evidence provides partial support to Happé et al.'s (2006b) theoretical account, according to which there may be a particular profile of "coexisting cognitive atypicalities" in ASD that persist across development. Adding the evidence from the investigation of the age-related differences beyond middle childhood (Study Three) in which cool working memory and inhibition never reached the performance level of neurotypicals in adolescence either, it could be argued that this evidence overall could suggest that ASD individuals might reach a performance ceiling at some point in some EF aspects (Ozonoff and McEvoy, 1994). The present data indicate that despite some significant age-related improvements in selective cool EF, the performance of the ASD mainly follows a *deviant* development. Nevertheless, these findings paint a more positive picture of EF development in ASD as they suggest the likelihood of a window of brain plasticity in ASD during middle childhood at least, in which developmental/ maturation processes of selective cool EF may be intact in ASD. In order for this to be explained, Luna et al.'s (2007) proposition, as already discussed earlier in Study Two (chapter 4), should be taken into account as it suggests that in case deficits in EF persist across a developmental phase, it could imply that impairments in the underlying EF brain mechanisms are not related to the brain developmental/ maturation processes. Adding this to the emerging developmental improvements found within ASD across middle childhood, it could be suggested that the developmental processes may be intact for ASD participants before entering adolescence.

This was the first study to examine the developmental changes of hot EF in ASD longitudinally and results indicated that only affective decision making but not delay discounting presented significant age-related gains in school-aged children with ASD. These findings are in line with previously reported age-related performance gains in the Iowa Gambling Task across childhood and adolescence (Hooper et al., 2004; Prencipe et al., 2011), providing support to developmental theories stating hot EF development would be protracted to the extended development of the ventromedial prefrontal cortex across middle childhood (underlying brain mechanism) (Segalowitz & Davies, 2004). Similar to cool EF discussed above, results showed that despite the emerging developmental improvements, children with ASD presented deficits in the IGT task relative to the control group that did not become less marked with age. Thus it also followed a deviant developmental pathway. Once again, these findings highlight the importance of the emerging developmental gains in affective decision making, despite the deviant development, as it suggests that developmental/maturation processes of the brain structures underpinning selective hot systems in ASD are present across middle childhood. This finding highlights the importance of middle childhood as a developmental period, considering the fact that results from Study Three indicated that affective decision making presented no further developmental improvements in adolescence in either group. Detailed explanations about the potential failure of the gambling task used in the present study to detect the subtle developmental changes of affective decision making in adolescence, have been provided in Studies Two and Three and will not be reiterated here. Besides tasks discrepancies though, it is likely that affective decision making may present improvements up to middle childhood and not adolescence. Hot delay discounting on the other hand was the only EF aspect found to demonstrate an intact profile and non-significant developmental changes in ASD (neither deviant nor delayed pattern) in middle childhood and adolescence. One should expect the delay discounting trajectory to progress across school age similar to the other hot EF aspect as children need to rely more on their control of impulsivity (tapped by delay discounting). Considering that Study Three also failed to find significant age-related changes in delay discounting in adolescence, it could be suggested that selective hot EF aspects such as delay discounting are likely to present rapid changes only during the preschool period (and not later on) and thus reach a performance ceiling in middle childhood in ASD.

Future longitudinal studies with several time points across middle childhood and adolescence in ASD are needed to clarify this issue.

**Research Question 4:** ***What are the similarities and/ or differences between performance-based EF measures and rating scales of "real-life" EF from school teachers of children and adolescents with ASD compared to typically developing peers (7-16 years)? Which of the two EF assessment methods is the strongest contributor of adaptive skills in ASD and typical development?***

The present thesis showed that performance-based EF measures and rating scales of "real-life" EF (as reported by teachers' participants) followed differentiated developmental patterns and presented weak correlations. Moreover it was found that only "real-life" EF ratings predicted adaptive skills in children and adolescents with and without ASD. This thesis built on previous studies suggesting that rating scales and performance-based EF measures do not tap the same cognitive construct (Toplak et al., 2013) by showing for the first time that the developmental pathways of these two different types of EF measures deviate from each other and that they do not predict the same social outcomes in ASD. More specifically, the patterns of development found for "real-life" EF inhibition and planning were different compared to the performance-based EF profiles of those aspects presented in Study Three providing support to the hypothesis that "real-life" EF may actually tap different cognitive constructs. Generally, age-related performance declines were found in several "real-life" EF domains such as inhibition, initiate, working memory, planning, organisation, self-monitor but not for EF emotional control and shift that presented non-significant alterations across age. These results suggest that several "real-life" EF difficulties are likely to increase during the transition to adolescence (from primary to secondary education). Finally, it was found that only "real-life" and not performance-based EF predicted adaptive skills over and above age and IQ in children and adolescents with and without ASD. The variability of the different EF approaches are potentially influenced by the complexity of the EF construct. Developmental differences could thus lie on the differentiated structure of the two types of EF measures with performance-based including contextual variables that may affect EF performance. More specifically, the strict structural nature of the laboratory settings may contribute to optimal performance of the performance-based EF in contrast to "real-life" environments that do not "naturally scaffold performance" (Wallace et al., 2016, p.88). Therefore "real-life" EF ratings may reveal EF deficits that might not emerge in laboratory settings. The present findings highlight the importance of not using these two types interchangeably during assessment and also provide the avenue to develop more ecologically valid approaches to EF assessment in ASD.

## 7.4. Contributions of findings to the literature

***Development of hot and cool (performance-based) EF in ASD: delay or deviance?***

EF is suggested to follow a protracted development throughout childhood, yet there is limited knowledge regarding the development of these abilities in school-aged children (middle childhood) and adolescents in ASD. This research contributed to existing literature as it clearly showed that the cool EF skills of inhibition, working memory and planning improve during school age but then present declines or pauses during adolescence in ASD, as only inhibition showed developmental gains beyond middle childhood. The ability of inhibition (tapped here by a response inhibition measure), despite being generally considered as not showing substantial improvement during school age, was found to demonstrate developmental changes, which may be apparent only when more sensitive measures are used. With regards to hot EF, this research provided limited evidence for improvements in hot processes in middle childhood (as only affective decision making presented developmental gains in both groups), while there were no significant developmental improvements in adolescence in any of the hot EF measures in ASD or typical development. Thus, the present research adds to background literature that cool and hot EF follow different developmental pathways in ASD and that hot EF may present a developmental arrest after middle childhood in ASD.

One of the most important findings of the present thesis was the demonstration of age-related improvements in cool EF in ASD across middle childhood which added to the current debate in ASD literature of whether EF deficits decline with age or persist throughout development in ASD. The few developmental studies to date have yielded mixed results with some reporting no significant developmental gains (Happé et al., 2006a; Ozonoff et al., 1994) and others finding significant performance improvements (Pellicano, 2007). Study Two showed that all cool EF (working memory, inhibition, planning) presented age-related improvements in middle childhood in ASD (and typical development) in line with imaging evidence about the myelinisation and maturation of the frontostriatal regions in this developmental phase (Bradshaw, 2001; Eslinger, 1996; Goldman-Rakic, 1987; Hale, Bronik, & Fry, 1997; Majovski, 1997). These results are in line with background theory suggesting that there may be substantial increments in EF occurring between the 7th and 9th as well as between the 11th and 12th year of life (Anderson, Anderson, & Lajoie, 1996). This pattern of evidence is an important contribution to ASD research as it demonstrates that cool EF maturation processes may be intact during middle childhood in ASD. Anderson (1998) suggested that the prefrontal cortex reaches maturity in early puberty which implies that this brain region is incompletely developed during childhood and could influence EF performance. Results from Study Three though indicated that only inhibition continued to improve until adolescence while working memory and planning presented declines and lack of changes respectively. Thus the present results further contribute to the ASD literature showing that after the significant gains of middle childhood, selective cool EF aspects may experience losses or no changes at all later on development.

The developmental trajectories can vary for different EF domains (Anderson, 1998; Archibald & Kerns, 1999; Klernberg, Klorman, & LahtiNuuttilla, 2001; Welsh & Pennington, 1988) which was supported by the present research showing that hot EF followed a differentiated developmental pathway. Contributing to the very limited background literature regarding the development of hot EF in ASD, Study Two showed that affective decision making presented some age-related improvements in ASD while performance in delay discounting did not present significant changes across school age. Building on Study Two, Study Three showed that neither delay discounting nor affective decision making presented significant differences cross-sectionally across younger or older participants (adolescents). These findings could suggest that only selective hot EF processes demonstrate some alterations during middle childhood and that it generally seems that hot EF (as measured at least by the present measures) seems to follow a developmental arrest beyond middle childhood.

***Distinction of cool and hot EF***

The findings presented in this thesis provide some preliminary evidence to current debate referring to whether one can consider the hot EF processes as distinct dimensions of EF as well as whether cool and hot EF processes form a unitary or fractionated construct. To date EF has been traditionally examined mainly under a purely cognitive lens, elicited under relatively abstract, decontextualized, non-affective conditions without taking into account the emotional and motivational aspects of EF (Peterson & Welsh, 2014). The present thesis was centred around the Zelazo and Müller's (2002) conceptual model proposing that EF and its underlying neural mechanisms should be distinguished into cool and hot EF skills (Zelazo & Carlson, 2012). Preliminary theoretical accounts in the early 90's posited that EF should be conceptualised as a more broad construct as it was found to facilitate not only cognitive control but affective control as well (the so called "hot" processes) (Zelazo and Müller, 2002). Some of the first proponents of this distinction were Metcalfe and Mischel (1999) who proposed that EF includes both cool and hot processes with the latter referring to the influence of emotion on behaviour regulated by the cool processes. Zelazo and Müller (2002) built on the initial model by Metcalfe and Mischel and suggested a different EF model in which hot and cool EF were clearly distinct processes regulated by different brain regions. According to this model, hot EF processes are evoked under motivationally significant, affective conditions while cool EF includes processes evoked under relatively abstract, non-affective situations (Zelazo, & Carlson, 2012). Despite being different, both EF processes work together in problem solving as a part of a more general adaptive function. The theoretical distinction between hot and cool EF has been quite a controversial topic while support for the existence of a multidimensional model has been mixed in typical development. Some studies in early childhood have supported a two factor model (Kim et al., 2014; Willoughby et al., 2011) while others failed to find evidence of distinct cool and hot domains of EF (Allan & Lonigan, 2014). In terms of later childhood and adolescence, most evidence suggests that cool and hot EF can present differentiated developmental trajectories and present weak correlations between them (Hooper et al., 2004; Prencipe et al., 2011). The present research has provided stronger evidence for a distinct EF model in ASD rather than typical development.

Starting with typical development, the present research only weakly supported the existence of distinct cool and hot domains of EF in typically developing participants due to mixed evidence. According to Welsh and Peterson (2014), the construct validity of hot and cool EF to date is traditionally examined by the inspection of their developmental patterns, by means of bivariate correlational patterns or more sophisticated statistical procedures such as confirmatory factor analyses and structural equation models. The present thesis showed indeed that cool and hot EF skills showed differentiation in development across middle childhood and adolescence but selective cool and hot tasks were significantly correlated and there was a lack of associations between the hot tasks in typical development. Divergent and convergent correlational patterns would likely indicate relatively independent constructs, such that cool and hot tasks should significantly intercorrelate within but not across domain (Welsh & Peterson, 2014). Contradicting previous research suggesting that cool and hot EF follow parallel developmental trajectories (Hongwanishkul et al., 2005; Kerr & Zelazo, 2004), Study Two (Chapter 4) indicated that while all cool EF presented developmental gains, only hot affective decision making and not delay discounting presented significant improvements after one year across middle childhood in typical development. Moreover, Study Three (Chapter 5) also showed that only the developmental trajectories of cool EF presented age-related gains from middle childhood up to adolescence while no developmental changes were revealed in the hot EF ones. Taking this evidence together, it seems that during middle childhood and adolescence, significant improvements are strongly evident mainly in cool EF which implies that the development of selective hot EF may pause beyond 5 years of life. Thus, it is likely that the developmental trajectory of hot EF follows a distinct, differentiated pathway with rapid changes and (statistically) significant improvements occurring mainly before 7 years of life (early childhood) in typical development. Hot and cool EF are thought to be regulated by different regions of the prefrontal cortex (Zelazo & Müller, 2002; Zelazo & Carlson, 2012), one of the last brain regions to reach maturity (Fuster, 2002; Steinberg, 2005). This may explain why cool and hot EF may become more differentiated with development (Bechara et al., 1998) since different cognitive abilities associate with more specialised brain regions (Karmiloff-Smith, 1994). However, evidence that may contradict the existence of distinct cool and hot EF domains in typical development was found in Study Three (Chapter 5) and showed that aspects of cool EF were correlated to aspects of hot EF only in typical development and not in ASD. Furthermore, only cool EF aspects were positively correlated to each other whereas hot EF skills were not interrelated. These hot EF skills (delay discounting and affective decision making), do not seem to be tapping the same underlying hot factor in typical development. It should be noted though that as this research is still in its infancy, understanding of the development and organisation of hot EF lags behind that of cool EF (Peterson & Welsh, 2014) and tasks such Iowa Gambling task (measuring affective decision making) have been criticised for involving attentional rather than EF abilities. Thus results from correlational analysis may reflect the failure to clearly elucidate which skills encompass hot EF in reality and how these relate to cool EF.

With regards to ASD, evidence from the present research revealed more clearly that hot and cool aspects are distinct EF domains. Studies Two (Chapter 4) and Three (Chapter 5) revealed that hot EF in ASD presented a deviant developmental trajectory relative to cool EF both across age and time. Results from the longitudinal study (Study Two) showed that the internal developmental trends of hot EF were not consistent with those of cool EF. More specifically, as with typical development, although all cool EF presented age-related improvements, only hot affective decision making but not delay discounting improved after one year in middle childhood. Building on this evidence, Study Three also indicated significant differences between the cross-sectional developmental trajectories of hot and cool EF in ASD from middle childhood to adolescence. Hot delay discounting and affective decision making presented developmental pauses contradicting most cool EF trajectories that presented changes in adolescence. The distinct developmental pathways of cool and hot EF in ASD, adds to better understanding of the heterogeneity of the neurocognitive impairments underpinning ASD and highlights the need of considering both domains in clinical practise in ASD as they may tap different cognitive domains. Further evidence of the validity of the hot and cool distinction came from the correlational analysis in Study Three in which both EF domains were found to be unrelated within the ASD group. The lack of significant associations between the two domains in ASD supports the theoretical model of Zelazo and Müller (2002) differentiating between the cool and hot processes that seem to contribute each unique variance to the developmental and cognitive profile of children and adolescents with ASD. Finally, another important finding that supports the hot-cool distinction in ASD is the different predictive patterns of each domain found in Studies Two and Three. Hot and cool EF aspects were found to predict different social/ developmental outcomes. For example in the longitudinal study (Study Two), results showed that early cool working memory predicted ToM false belief overall in both groups, but early hot delay discounting predicted ToM mental state/emotion recognition only in the ASD group. These significant concurrent associations and links across time between particular EF aspects and ToM imply that the degree to which each domain is related or not to different outcomes supports the notion for separate cool and hot EF (Welsh & Peterson, 2014). Future longitudinal studies across childhood and adolescence are warranted as they will hopefully better highlight the brain structure of cool and hot EF in ASD.

### *The link between EF and ToM*

The present study, in addition to contributing to the current literature on EF development and conceptualisation models, has also aided clarification of the link between EF and ToM across middle in ASD and typical development. There is an increasing number of studies studying the nature of the EF-ToM relation but they have all focused on early childhood and cool EF aspects. In line with the limited number of studies in middle and later childhood both in typical development (Austin et al., 2014), and ASD (Joseph et al., 2005), the findings from the current thesis (Study Two) show that both cognitive domains demonstrate significant gains in middle childhood and that these developmental gains in EF and ToM are intertwined. Building on the current theoretical literature surrounding the nature of the functional relationship of ToM and EF, the present research examined the longitudinal association between ToM and EF, at the level of hot and cool aspects across middle childhood in ASD and typical development. Results revealed an evidence of an asymmetric relationship in both groups: children's early EF was a significant predictor of later ToM over a year while there was no evidence of early ToM predicting later EF in children with and without ASD. Links remained significant even when age, IQ and early EF were controlled. The lack of a reciprocal link between EF and ToM is in line with previous relevant studies in ASD (Pellicano, 2007; Tager-Flusberg & Joseph, 2005) and typical development (Austin et al., 2014; Carlson et al., 2004; Flynn, 2007; Hughes & Ensor, 2007) which demonstrated the important role EF may play in the ToM development.

Taking this longitudinal evidence together, it could be suggested that individual differences in initial (early) EF skills influence children's later performance on ToM tasks. This pattern of findings support an expression account of ToM-EF relation (i.e. successful performance in ToM false belief/ mental states reasoning requires some level of EF capacity; Moses, 2001). However, due to the longitudinal nature of the present data, the functional relation between EF and ToM seems to go deeper than this. These finding suggest that EF provides a platform for the emergence and development of ToM in both groups, supporting the theoretical account of Russell (1996) according to which "children's direct experience of the intentional nature of actions leads to advancement in their mental state awareness". The failure of early ToM to predict later EF scores speaks against the opposite theoretical position of Perner and Lang (1999) stating that understanding of the representational nature of the mind is a prerequisite that leads to improved self-control (EF). The present results also contradicted Ozonoff et al.'s (1991) proposition that there may be a bi-directional relation between EF and ToM. Russell specifically argues that children are enabled to generate successful reflections on other perspectives only when they are in position to monitor their actions. Applying this model in ASD, it could be assumed that potential early disruptions, as in EF, may have a crucial impact on children's expression of self-awareness (ToM) (Pellicano, 2007; Russell, 1996). Further evidence on this theoretical view derives also from a training study in ASD (Fisher & Happé, 2005) examining the causal link between EF and ToM. Two groups of school-aged children (6-15 years) with ASD were trained on either EF or ToM and then re-evaluated both skills a week and two months later. It was found that ToM performance improved for children with ASD who had received an EF training two months earlier but no similar performance gains occurred on EF tasks of children that were trained on ToM at intake.

Another very interesting theoretical point though, noteworthy in the present study, is Hughes' (1998b) (see also Lewis & Carpendale, 2009), proposition that the developmental EF gains may have knock-off effects on ToM. In other words, EF may influence development of ToM mechanisms indirectly, through social contact. Hughes believed that EF are likely to facilitate social interactions which in turn require children to be able to monitor their actions and act with volition. Effective social interactions subsequently have positive implications for the development of ToM (Hughes & Leekam, 2004). Several of the participating children were recruited from mainstream schools where they have the opportunity to interact with children without ASD. Thus, another potential explanation of the reported EF-ToM link here could be the influence of the EF developments on children's social interactions which might have led to progress in ToM. Conversely, if children exhibit disruptions in early EF, this may have a negative effect on social interactions which then disturb their sociocognitive development (ToM). Although the scenario of EF indirectly influencing children's developing ToM is quite likely to occur, there is no study having examined potential sources of individual differences in the developing EF skills of children with ASD. It would be crucial for future studies to take both experimental and observational children's measures into account as this may aid in better identifying the direct or indirect EF effects on ToM in ASD and typical development.

Furthermore, results from Study Two add to the current literature by showing that not only cool but hot EF as well may serve as a risk factor for negative effects on the development of ToM (Hughes et al., 2000). More specifically, findings from Study Two showed that both cool and hot (delay discounting) EF were linked to ToM across middle childhood after age, IQ and Time 1 EF abilities were controlled. Cool EF was found to correlate with ToM in both groups across middle childhood while hot delay discounting was linked to ToM only in the ASD group supporting (to a degree) Zelazo's et al., (2005) proposition that hot EF may be more central than cool EF to ToM in ASD. As suggested by previous research, hot EF and ToM are likely to be regulated by the same prefrontal cortex medial regions (Sabbagh et al., 2009; Zelazo et al., 2005). Therefore, current findings corroborate to an extent that the underlying brain mechanisms of selective hot processes and ToM share such a developmental relation in ASD across middle childhood. Delay discounting is linked with the emergence of ToM mental state/ emotion recognition because children with ASD may require more "hot" motivational or emotional processes in order to understand the mental states of others (Zelazo et al., 2005) across middle childhood. However, as only hot delay discounting and not affective decision making were linked to ToM, the current findings need to be interpreted cautiously and as noted above they provide some support to the view that some hot EF processes may be more strongly associated with ToM in ASD due to their joint association with the medial regions of the prefrontal cortex (Siegal & Varley, 2002; Zelazo et al., 2005) and their emotionally significant nature (Zelazo & Cunningham, 2007; Zelazo et al., 2005).

***Real-life vs Performance-based EF***

The present thesis adds to a debate of the background literature of whether performance-based and "real-life" rating scales of EF assess the same or distinct constructs of EF. Generally the association between performance-based measures and rating scales have been found to be weak (Anderson et al., 2002; Mahone et al., 2002; ten Eycke & Dewey, 2016; Toplak, West, & Stanovich, 2013). Furthermore, a recent meta-analysis of 20 studies (Toplak et al., 2013) that compared these two types of EF measures showed that only 24% of the reported correlations were statistically significant. This failure to find significant associations was initially attributed to performance-based measures lacking ecological validity. It was thus suggested that performance of participants (especially those of clinical populations) in research settings with low distraction and strict structure could not actually reflect the "real-life" application of EF (McAuley et al., 2010; Roth, Isquith, & Gioia, 2005). Study Four though showed that performance-based and "real-life" EF ratings follow different developmental trajectories and do not predict the same behavioural/ social outcomes implying that the two types may in reality assess different cognitive constructs. Toplak et al. (2013) suggest that performance-based EF measures assess the algorithmic level of cognitive analysis which focuses on the efficiency of information processing mechanisms (e.g., working memory). On the other hand, the "real-life" rating scales of EF assess the reflective level of cognitive analysis that integrates the goals and beliefs of the examinees "into an optimal decision-making process, and success in this goal pursuit" (Toplak et al., 2013, p.138). The findings of this thesis support previous imaging research that found different neuroanatomical correlates for behavioural ratings (as measured by the BRIEF) and performance-based EF measures (Faridi et al., 2014). The fact that EF rating scales perhaps measure different cognitive constructs -to neuropsychological tests- should not mean that their validity is questioned. There is converging evidence to suggest that rating EF scales capture the subtle EF profiles of developmental disorders as reflected in everyday functioning (Isquith, Roth & Gioia, 2013). Furthermore, there is a growing body of research suggesting that although both measures are substantial predictors of social or behavioural outcomes (e.g. academic skills; Locascio, Mahone, Eason, & Cutting, 2010; Waber et al., 2006), "real-life" EF ratings show a greater capacity to predict clinical symptoms related to developmental disorders (e.g. ADHD, ASD) (Miranda et al., 2015). Findings of performance-based and rating scales of EF capturing some aspects of EF each and relating to important real-word functioning such as ToM and adaptive skills, highlight their mutual contribution to furthering our understanding of children's developmental functioning. A multilevel approach of EF assessment by addressing both types of measures seems necessary, and would be more informative than capturing only the variance of one or another type of measure. Children's assessment models should view development within children's natural environment and address simultaneously two levels of assessment: high-order neuropsychological EF aspects as tapped by performance-based measures and "real-life" behavioural manifestations measured by rating scales. Thus as both cognitive levels of analysis are important for clinical practice, these measures should not be addressed interchangeably as parallel indicators of EF performance either in research or educational assessments. Performance-based EF measures combined together with rating scales like the BRIEF, could serve as a valuable source of information for screening cognitive difficulties of developmental disorders by providing a more complete and ecological profile of the strengths and limitations of children.

### 7.5. Limitations

The present thesis made some novel contributions to the ASD literature as it was the first to assess the development of both hot and cool EF and their cross-sectional and longitudinal associations to ToM in typical development and ASD. The current findings however should be considered in the light of limitations. Firstly, findings from studies (i.e. 3 and 4) in which the developmental trajectories approach was employed need to be interpreted in caution due to statistical limitations inherent in such cross-sectional designs. Fundamentally, development is a dynamic process of change and thus better observed in longitudinal studies. Having said this, it is likely that the interpretation of the effect of age on EF measures using cross-sectional trajectories may be -inevitably- confounded by individual differences (i.e. different sampling at different age points). More specifically, participants in Study 3 for example may have differed on their EF tasks performance due to some of them being older or because other variables (e.g. verbal IQ) were not controlled for. Similar to this, one may also argue that the trajectories of "real-life" EF (Study 4) may perhaps reflect more the different perceptions of teachers at different ages (childhood vs adolescence) than actual developmental changes. For this reason, future longitudinal studies are warranted in order to validate the between-group differences in the developmental trajectories of EF as found using these cross-sectional techniques.

Due to the convenience sampling approach followed in all four studies, the participating children and adolescents (with high-functioning ASD) may not represent the broader ASD population. The present thesis also included only 7 to-16- year old participants; hence it remains to be found whether these results (especially the ones related to the emerging associations between hot delay discounting and ToM) can be generalised to younger children and adults across the autism spectrum. Second, although the sample size of the ASD group was quite large compared to previous relevant EF studies (e.g. Bock et al., 2015; Happé et al., 2006a; Pellicano, 2007, 2010), the present results, especially the interaction effects reported in all studies need to be replicated by future studies with larger sample sizes (in both groups) as interactions may have lacked statistical power to detect smaller effects. Furthermore, the uneven number of children and adolescents in both groups due to recruiting difficulties did not allow the allocation of participants into age cohorts which could have revealed important developmental information (i.e. which are the crucial age and/or time points across development). Another limitation of the sample size was that more advanced statistical techniques (such as factor analysis) could not be conducted to investigate for example the existence or not of the hot and cool distinction in ASD and typical development.

An important limitation of the present thesis was also the lack of a validated screening tool in order to corroborate the provided clinical diagnostic reports of ASD. However, it was ensured that all ASD participants held an official clinical diagnosis by a qualified clinician using DSM-IV or DSM-V criteria (American Psychiatric Association, 1994, 2013) and qualified for a "broad ASD" on the Autism Diagnostic Interview/ Autism Diagnostic Interview-Revised (ADI/ ADI-R; Le Couteur et al., 1989; Lord, Rutter, & Le Couteur, 1994) and/ or the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000), in accordance to National Institute for Health and Clinical Excellence (NICE, 2011) guidelines.

Another limitation of the present research was that the only aspects of ToM employed here were the false belief knowledge and mental state/ emotion recognition ability which cannot be considered the only important ToM tasks. However, other aspects of ToM may relate to EF across age or time as well. Follow up research should consider investigating the relation of both hot and cool EF and ToM addressing other aspects of ToM such as second-order ToM (Perner & Wimmer, 1985), the strange stories (Happé, 1994) or the Faux Pas test (Baron-Cohen et al., 1999). Moreover, as ToM is a diverse construct including a broad range of mechanisms, clear conclusions about the role of hot EF to the wider ToM cannot be drawn as results from Studies One, Two and Three showed that hot EF delay discounting significantly predicted only one of the two ToM measures.

A final limitation of the present research was that some of the EF tasks used here, despite being widely used and well validated may not have been sensitive enough to developmental changes in EF across such a broad age range of the present thesis. For example, performance especially on tasks assessing hot EF abilities did not present significant changes between children and adolescents with and without ASD. This, in conjunction with the lack of significant changes of the control group after one year in school age (Study Two) in ToM false belief measure may imply ceiling effects. Future research should focus on developing EF and ToM tasks that are developmentally sensitive within a wide age range, especially at the transition from middle childhood to adolescence.

## 7.6. Conclusions

This chapter presented an overall discussion of the results, relating them to the four research questions stated at the end of Chapter One and linking them to the wider literature. In addition, the limitations of the present study were also presented. First, the findings from the present study showed that hot EF are associated with selective ToM mechanisms, over and above cool EF in school-aged children (middle childhood) with and without ASD. This evidence highlights that considering the role both hot and cool EF play in ToM abilities in individuals with ASD may aid in gaining a greater understanding of the higher-order neurocognitive deficits underlying difficulties with social interaction for the ASD population. These findings underline the need to assess hot and cool EF in clinical practice and future ASD research as it seems that they may both contribute to enhancing diagnosis or better informed intervention projects. Furthermore, the present study demonstrated that children with ASD present significant developmental changes during school age (middle childhood) in cool (working memory, planning, and inhibition) and selective hot EF (affective decision making) skills. These data highlight the need to shed more light on the underlying brain structures as the reported impairments in EF are likely not related to the maturation processes in middle childhood in ASD. Furthermore, the present study contributed support to the theoretical account suggesting that EF influences the development of ToM and not vice versa in ASD and typical development across middle childhood (support to an emergence account; Russell, 1996, 1997) and further expanded this strong longitudinal associations of ToM to hot EF as well. Results suggested that specific hot EF skills (delay discounting) can also provide a platform for the emergence of ToM across middle childhood in ASD. Research into hot EF in childhood is receiving growing attention but knowledge about its developmental trajectory beyond early childhood still lags behind that of cool EF both in typical development and ASD. Study of the developmental trends of hot and cool EF and their longitudinal associations to ToM in middle childhood is necessary. This important developmental period has received limited attention despite being crucial for children's development. Such developmental data may aid in achieving a better theoretical understanding of the link between cognition and behaviour in typical development and of the development of higher-order cognitive impairments being a risk factor for poor developmental/ social outcomes in children with ASD. Evidence from the cross-sectional developmental trajectories of EF from childhood to adolescence in ASD painted a more negative picture of the ASD cognitive EF profiles as they were characterised either by declines or persisting deficits that did not improve in adolescence. However, as these data are derived from a cross-sectional design they should be interpreted cautiously and highlight once again the need for future longitudinal studies within early and later adolescence that could clarify whether improvements can also take place in adolescence across time. The significant results relating to the existence of a distinction between hot and cool EF, mainly in the ASD group, may contribute to our better theoretical understanding of the phenotypes of children and adolescents with ASD. However, as affective decision making was not correlated to delay discounting or cool EF in either group, it is suggested that more focus should be turned on identifying what cognitive processes fall under the umbrella of hot EF. Finally, the different developmental patterns followed in "real-life" EF ratings in comparison to performance-based measures in conjunction with the differentiated predictive patterns of social outcomes (i.e. adaptive skills) between the two types of measures (only the "real-life" ratings predicted adaptive skills and not the performance-based EF tasks) emphasises the need for researchers to consider a variety of measures in EF research rather than assuming the same underlying factors are tapped by each available measure. The comparison of the results across informants and direct performance is important since it is likely to measure different cognitive domains. Thus the usage of both in clinical research can enhance understanding of the heterogeneous phenotype of ASD.

### 7.7. Implications and Future Directions

The research findings presented in the current thesis may have important theoretical implications towards a better understanding of the current models of EF development and of the links between EF and ToM. The present thesis indicates that cool and hot EF systems present differentiated developmental patterns to each other and may be distinct in children and adolescents with ASD. These findings also suggest that both hot and cool EF are still linked to ToM across middle childhood in typical development and ASD. Such information may aid in overcoming limitations of current conceptualisation models and contribute more clarity to the cognitive and social development of ASD individuals.

These findings may have implications not only for the theoretical understanding of the cognitive and social development, but also for assessment and interventions. Cool EF has been suggested to be associated with academic success and classroom behaviour in young children (Brock, Rimm-Kaufman, Nathanson, & Grimm, 2009; Garner & Waajid, 2012). The present thesis also showed that hot EF is associated with social behaviour, especially in ASD, and should be considered an important factor to target in interventions or diagnosis. Also, training studies should take both cool and hot EF into account when planning cognitive assessments and target to boost EF aspects that were shown here to facilitate the ToM mechanisms of children and adolescents with ASD; this could yield significant results in terms of academic achievement and socialisation. These interventions or training studies that can improve EF should be more successful if they employ a variety of cool and hot EF skills since ASD participants in the present thesis showed significant gains in several EF across middle childhood (school age). Investigations of EF interventions should also employ a wide range of EF measures with both performance-based and “real-life” EF measures in order to comprehensively assess the change in EF. The present thesis showed that both types are weakly related and follow a differentiated developmental pattern, providing support to the theoretical views proposing that neuropsychological tests and rating scales of EF do not measure the same cognitive construct. Such data highlight the complementary contributions of both to further understanding the heterogeneity of EF deficits. New tasks that tap both EF types should be developed. For example, Parsons and Carlew (2016) have employed modern technology lately that allows for a more targeted assessment approach of EF, providing new measures of traditional performance-based EF measures contextualised within "real-life". Their paradigm utilised virtual reality that adapted a Stroop-like task within a classroom environment, and showed that including potential distractors within the task (in an attempt to stimulate the "real-life" environments) may reveal deficits in ASD relative to similar tasks without distractors. Combining the traditional neuropsychological assessment with the ecological validity of natural settings through the help of technology could take advantage of the strengths of all different approaches.

The findings from the present thesis set out important directions for future research. Firstly, it is apparent that there is limited understanding of hot EF, which is partially reflected due to the unavailability of tasks measuring hot EF, especially in childhood. Thus study of cool and hot EF is quite challenging for researchers. Focus should be turned on developing more suitable tasks which can help to better identify hot EF and what processes fall under the umbrella of "hot processes". Further, the association between hot and cool EF skills is in great need of further investigation across childhood and adolescence both in ASD and typical development, especially focusing on identifying whether it is a unitary or multidimensional construct. Future longitudinal studies of more than two time points, employing structural equation and factor analysis could shed more light on the hot-cool EF distinction. Such knowledge could aid in better understanding the underlying nature of EF. It would be also important for future studies to include several ToM measures. The present thesis only considered false belief understanding and mental state/ emotion recognition. However these tasks are not the only essential measures and several other ToM tasks such as the strange stories (Happé, 1994), or the Faux Pas Test (Baron-Cohen, O'Riordan, Jones, Stone, & Plaisted, 1999) could be taken into account.

The final and most important focus for future research should be the design of more longitudinal studies, beyond early childhood. The present study showed for example that middle childhood represents an important period in the development of children's cognitive and social abilities that change with development. The present study followed students only across two time points but it would be crucial for children to be followed over a longer period of time (three or more time points), up to adolescence as this would provide a better understanding of the underlying maturation and developmental processes of EF and ToM in ASD and typical development. Future research should also turn focus to EF and aging in ASD as very few studies have assessed the aging impact on cognitive control (Geurts & Vissers, 2012; James et al., 2006). In conclusion, studying how cognitive abilities develop and influence other developmental landmarks may lead to better intervention services and more targeted educational programs.

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## 9. Appendix A
## Recruitment Letters to Schools

Recruitment Letter/Information Sheet and Consent Form – Head teacher

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

Evangelia Kouklari (PhD student)
Department of Psychology and Social Work and Counselling
University of Greenwich
Bronte B312, Avery Hill Road, Eltham, London, SE9 2UG
Contact details

Supervisors:
Dr Stella Tsermentseli

Dr Claire Monks

Dear <insert head teacher's name>,

I am an MPhil/PhD student at the University of Greenwich and I am currently conducting a study into the role of executive function within the Autism Spectrum. My research focuses on the developmental trajectories of executive function in children and adolescents typically developing and with Autism Spectrum Disorder (ASD) as well as the association of executive function to theory of mind and adaptive skills across time. Executive function is an umbrella term for cognitive abilities that allow for purposeful, goal directed behaviour. This includes the ability to plan behaviour, think flexibly about a situation and to follow rules. Theory of mind is the ability to understand why other people behave the way they do. It is hoped that this research will identify patterns of developmental trajectories across the spectrum and may yield crucial contributions to develop theories of plasticity, create sophisticated screening tools or plan successful intervention targets. The expected results could help us improve the consequences of executive dysfunction in daily living of children with ASD.

I aim to recruit children and adolescents aged between 7 and 16 years both typically developing and with ASD (need to have an official diagnosis). I aim to specifically recruit high functioning ASD participants (General Intelligence score >70).

The first part of the study will take place in <INSERT MONTH> 2015 where I will come into the school for a few days during which children will be asked to take part in several fun and age appropriate executive function and theory of mind tasks.

The second part of the study will follow a subsample of pupils only with ASD of the first study after a 12 month period; thus I would like to come into the school 2 times. Teachers of the children participating will be asked to fill two questionnaires regarding their students' behaviour.

In addition, the tasks children will have to undertake will be spread across 2 sessions. The school would be asked to provide a quiet room or area in which children could individually complete the tasks with the researcher.

I am writing to ask your permission to approach teachers, teaching assistants and parents/caregivers of children in the relevant classes about this study. Parents/caregivers will be asked to provide written consent that they wish for their child to take part in the study. If you are happy for me to contact those concerned about the research please complete and return the consent form below. If you would like to discuss the study further or have any questions please do not hesitate to contact me. I also have a DBS clearance.

The data from this study will be written up as part of my thesis and may be published. All data will be treated confidentially and all data will be published anonymously; the name of the school, teachers and children will not be published. Should any of the participants wish to withdraw their data from the study they will have up until the <INSERT DATE> to withdraw their data.

Your school's participation in this research would be greatly appreciated. To thank you for your participation I will provide you with a summary of the findings of the research once it is completed.

Thank you for taking the time to consider my research. I will be following up this letter with a phone call in two weeks.

Kind Regards,
Evangelia Kouklari

**Study:** Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder.

| **I am willing for the teachers, teaching assistants and parents/caregivers of children in the relevant classes in my institution to be approached about participating in the above mentioned research study.** | |
|---|---|
| **School** | |
| **Head teacher** | |
| **Signature** | |
| **Date** | |

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

Evangelia Kouklari (PhD student)
Department of Psychology, Social Work and Counselling
University of Greenwich
Bronte B312, Avery Hill Road, Eltham, London, SE9 2UG
Contact details

Supervisors:
Dr Stella Tsermentseli

Dr Claire Monks

Dear <insert teacher's/teaching assistants name>,

Your school has given permission for me to contact you regarding my research.
I am an MPhil/PhD student at the University of Greenwich and I am currently conducting a study into the role of executive function within the Autism Spectrum. My research focuses on the developmental trajectories of executive function in children and adolescents typically developing and with Autism Spectrum Disorder as well as the association to theory of mind and adaptive skills across time. Executive function is an umbrella term for cognitive abilities that allow for purposeful, goal directed behaviour. This includes the ability to plan behaviour, think flexibly about a situation and to follow rules. Theory of mind is the ability to understand why other people behave the way they do. It is hoped that this research will identify patterns of developmental trajectories across the spectrum and may yield crucial contributions to develop theories of plasticity, create sophisticated screening tools or plan successful intervention targets. The expected results could help us improve the consequences of executive dysfunction in daily living of children with ASD.

I aim to recruit children and adolescents aged between 7 and 16 years both typically developing and with ASD (need to have an official diagnosis). I aim to specifically recruit high functioning ASD participants (General Intelligence score >70).

The first part of the study will take place in <Insert month> 2015 where I will come into the school for a few days during which children will be asked to take part in several fun and age appropriate executive function and theory of mind tasks.
The second part of the study will follow a subsample of pupils only with ASD of the first study after a 12 month period; thus I will come into the school 2 times. As a teacher, if your students participate in the study, you will be asked to fill two questionnaires regarding their behaviour.
In addition, the tasks children will have to undertake will be spread across 2 sessions. The school would be asked to provide a quiet room or area in which children could individually complete the tasks with the researcher. I also have DBS clearance.

The data from this study will be written up as part of my thesis and may be published. All data will be treated confidentially and all data will be published anonymously; the name of the school, teachers and children will not be published. Individual child data will not be available. Should you wish to withdraw your data from the study you will have up until the <insert date> to withdraw your data. Withdrawal of your data will not affect your standing with the school or university.

Your participation in this study would be greatly appreciated. If you would like to participate in the study please complete the attached consent form and return it to me, retaining a copy for yourself. If you do not wish to participate it will not affect your standing with your school or the University of Greenwich. If you have any questions do not hesitate to contact me. To thank you for your participation I will provide you with a summary of the findings of the research once it is completed.

Thank you for taking the time to consider my research.

Kind Regards,
Evangelia Kouklari.

UNIVERSITY of GREENWICH

**PARTICIPANT CONSENT FORM**
**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder.**

To be completed by the participant (teacher/teaching assistant).

- I have read the information sheet about this study
- I have had an opportunity to ask questions and discuss this study
- I have received satisfactory answers to all my questions
- I have received enough information about this study
- I understand that I am free to withdraw from this study:
    - At any time (until such date as this will no longer be possible, which I have been told)
    - Without giving a reason for withdrawing
    - (If I am, or intend to become, a student at the University of Greenwich) without affecting my future with the University
- I understand that my research data may be used for a further project in anonymous form, but I am able to opt out of this if I so wish, by ticking here. ☐
- I agree to take part in this study

| | |
|---|---|
| Signed (participant): | Date |
| Name in block letters: | |
| Signature of researcher: | Date |
| This project is supervised by:<br><br>Dr. Stella Tsermentseli<br>Dr. Claire Monks | |
| Researcher's contact details:<br><br>Evangelia Kouklari | |

Recruitment Letter/Information Sheet – Parent/Caregiver

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

Evangelia Kouklari (PhD student)
Department of Psychology, Social Work and Counselling
University of Greenwich
Bronte B312, Avery Hill Road, Eltham, London, SE9 2UG
Contact details

Supervisors:
Dr Stella Tsermentseli

Dr Claire Monks

Dear Parent/Caregiver,

Your child's school has agreed to participate in my research study and I am writing to inform you of the study and ask for your consent for your child to participate in the study.

The study is being carried out to explore the development of certain types of brain processes such as reasoning and planning in children and adolescents, with or without Autism Spectrum Disorder (ASD). Children who participate in the study will be asked to complete a selection of age appropriate tasks with myself at school. This study is not a medical study. The tasks are designed to be fun games. I will be coming into the school two times across the next 12 months and each time I will ask those children participating in the study to complete the tasks.
Your child's participation would be greatly appreciated. For more detailed information about the study, please see the information sheet overleaf. If you have any questions please do not hesitate to contact me. If you are happy for your child to participate please complete the attached consent form and return it to your child's class teacher. I have DBS clearance.
Thank you for taking the time to consider my research.

Kind regards,
Evangelia Kouklari

**Information Sheet**

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

This study is being carried out as part of my MPhil/PhD and investigates certain types of brain processes such as reasoning and planning in children and adolescents, especially those within Autism Spectrum Disorder (ASD). The research explores the development of children's executive function and the relationship to theory of mind abilities and adaptive skills across time. Executive function is the ability to control behaviour. For example, it includes the ability to filter distractions and plan behaviour. Theory of mind refers to the ability to understand why other people behave the way they do. It is hoped that this research will identify patterns of developmental trajectories across the spectrum and may yield crucial contributions to develop theories of plasticity, create sophisticated screening tools or plan successful intervention targets. The expected results could help us improve the consequences of executive dysfunction in daily living of children with ASD.

The study will involve children being asked to take part in a selection of fun and age appropriate tasks, which look at children's executive function and theory of mind skills. Children will complete these tasks with me (Evangelia Kouklari) at their school (*I have DBS clearance*). The tasks are designed to be like games. For example, the fish/shark task is a computer task that asks children to catch fish by pressing a button each time a fish appears on the screen, but to avoid catching sharks by not pressing the button when they see a shark. For more details please contact me. These tasks are not tests of children's abilities and individual child data will not be made available. The tasks will be spread across two sessions, with each session lasting no longer than 30 minutes. In addition, as part of the study teachers will be asked to complete a questionnaire about the children behaviour. I will return to the school again after 12 months to complete the tasks again with the children.

The data from this study will be written up as part of my thesis and may be published. All data will be treated confidentially and all data will be published anonymously; the name of the school, teachers and children will not be published. Should you wish to withdraw your child's data from the study you will have up until the <insert date> to withdraw their data.
Withdrawing your child's data from the study will not affect your or your child's standing with the school or the university.

If you are happy for your child to participate in the study please complete the consent form below and return it to your child's class teacher. If you have any questions please do not hesitate to contact me. If you would like to see a summary of the findings of the research once it is completed please let me know.
Thank you for taking the time to consider my research. Your child's participation would be greatly appreciated.

UNIVERSITY of GREENWICH

**PARTICIPANT CONSENT FORM**

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder.**

To be completed by the parent/caregiver of the child participant.

| | |
|---|---|
| • I have read the information sheet about this study<br>• I have had an opportunity to ask questions and discuss this study<br>• I have received satisfactory answers to all my questions<br>• I have received enough information about this study<br>• I understand that I am free to withdraw from this study:<br>  ○ At any time (until such date as this will no longer be possible, which I have been told)<br>  ○ Without giving a reason for withdrawing<br>  ○ (If I am, or intend to become, a student at the University of Greenwich) without affecting my future with the University<br>• I understand that my research data may be used for a further project in anonymous form, but I am able to opt out of this if I so wish, by ticking here. ☐<br>• I agree for my child to take part in this study | |
| Signed (parent/caregiver): | Date |
| Name in block letters: | |
| Child's name in block letters:<br>Child's class: | |
| Signature of researcher: | Date |
| This project is supervised by:<br><br><u>Dr. Stella Tsermentseli</u><br><br><u>Dr. Claire Monks</u> | |
| Researcher's contact details:<br><br><u>Evangelia Kouklari</u> | |

Verbal Information Read to Children

**Verbal Information read allowed to each child at the beginning of each assessment session.**

Hello <child's name>.

My name is Evangelia and I want to know whether you would like to play some games with me today. I have asked your parents and your teacher and they have said it is ok, but if you don't want to play then that is ok too.

I am interested in how children and young people play these games. Today we are going to play [insert number] games. I will explain each game to you and then we will play. It doesn't matter how you do in the games. There are no right or wrong answers. The games are meant to be fun.

Everything that you tell me while we play the games is just between me and you. I won't tell anybody what you have told me.

If you want to stop playing for any reason just let me know.

Do you have any questions?

Would you like to play? *(If the child states they would like to play then this is seen as verbal assent. If the child states they do not want to play then the experimenter will thank them and take them back to their class.)*

**Verbal Information read allowed to each child at the end of each assessment session.**

We have finished all the games we are going to play today. Thank you very much for playing the games with me. You did really well.

Do you have any questions that you want to ask me before you go back to your lesson?

Thank you.

Debrief – Teacher

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

Thank you for taking the time to participate in my research. Your participation is greatly appreciated.

I am carrying out this study as part of my Psychology MPhil/PhD programme. The purpose of this study was to investigate the development of executive function and the association to theory of mind and adoptive skills in children and adolescents with or without Autism Spectrum Disorder (ASD) across time. Executive function is an umbrella term for cognitive abilities that allow for purposeful, goal directed behaviour. Theory of mind is the ability to understand why other people behave the way they do. My research explores whether ASD children's executive function follow a different development compared to typically developing peers and whether EF abilities are associated with theory of mind across time.

The questionnaires you completed for each child in your class will be used to gain a measure of children's EF abilities in a more natural context such as the classroom and will be compared to children's individual performance on each EF test.

The data from this study will be written up as part of my thesis and may be published. Your questionnaire responses are confidential and anonymous. Data will be published anonymously; the name of the school, teachers and children will not be published. Individual child data will not be available or published. Data will be kept for 7 years and will then be securely destroyed.
Please visit http://www.scholastic.com/parents/resources/article/disabilities-special-needs/explaining-executive-function
http://www.autismspeaks.org/family-services/tool-kits/asperger-syndrome-and-high-functioning-autism-tool-kit/executive-functioni
for more information about Executive Function and Theory of Mind in children and young people with or without ASD.

Should you wish to withdraw your data from the study please complete and return the form below. You will have up until the <insert date> to withdraw your data. Withdrawal of your data will not affect your standing with the University of Greenwich.

If you have any questions concerning the research please feel free to contact myself (Evangelia Kouklari), or one of my supervisors (Dr Stella Tsermentseli or Dr Claire Monks).

Thank you for taking the time to participate in my research.

**Study:** Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder.

**I wish to withdraw my data from the above study.**

| | |
|---|---|
| Name | |
| Signature | |
| Date | |

Debrief – Parent/Caregiver

**Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder**

Thank you for letting your child participate in my research. Your child's participation is greatly appreciated.

I am carrying out this study as part of my Psychology MPhil/PhD programme. The purpose of this study was to investigate the development of executive function and the association to theory of mind and adoptive skills in children and adolescents with or without Autism Spectrum Disorder (ASD) across time. Executive function (EF) is an umbrella term for cognitive abilities that allow for purposeful, goal directed behaviour. Theory of mind is the ability to understand why other people behave the way they do. My research explores whether ASD children's executive function follow a different development compared to typically developing peers and whether EF abilities are associated with theory of mind across time.

The second part of the study followed children over 12 months. Teachers and parents completed questionnaires for each child that participated which measured levels of EF in a natural context which will be compared to children's individual performance on the EF measurements. Children completed several age-appropriate, fun tasks measuring their executive function and theory of mind skills. Children's development of executive function and theory of mind/adaptive skills performance will be explored to see their trajectory and individual growth and if there is an association between these abilities.

The data from this study will be written up as part of my thesis and may be published. All data is confidential and anonymous. Data will be published anonymously; the name of the school, teachers and children will not be published. Individual child data will not be available or published. Data will be kept for 7 years and will then be securely destroyed.
Please visit http://www.scholastic.com/parents/resources/article/disabilities-special-needs/explaining-executive-function
http://www.autismspeaks.org/family-services/tool-kits/asperger-syndrome-and-high-functioning-autism-tool-kit/executive-functioni
for more information about Executive Function and Theory of Mind in children and young people with or without ASD.

Should you wish to withdraw your child's data from the study please complete and return the form below. You will have up until the <insert date> to withdraw your child's data. Withdrawal of your child's data will not affect your own or your child's standing with University of Greenwich.

If you have any questions concerning the research please feel free to contact myself (Evangelia Kouklari) or one of my supervisors (Dr Stella Tsermentseli, Dr Claire Monks).

Thank you for letting your child participate in my research.

**Study:** Developmental trajectories of Executive Function in children and adolescents with Autism Spectrum Disorder.

**I wish to withdraw my child's data from the above study.**

| | |
|---|---|
| Child's Name | |
| Parent/Caregiver<br>Signature | |
| Date | |

# 10. Appendix B

Examples of the measures used in the present study and described above.

*Reading the Mind in the Eyes test (sample images):*

hate surprised

kind cross

“Please look at the image carefully and choose one of the four options around” unkind cross

surprised sad

“Please look at the image carefully and choose one of the four options around”

*Sandbox test (sample images)*

**1)**

Sanne and her dad go to bury flowerbulbs. Sanne's dad buries a flowerbulb in the sandbox. In the picture you see where he buried the flowerbulb: at the location of the cross.


**0 cm**

After that, Sanne's dad goes to the barn to get a watering-can. In his absence Sanne decides to move the flowerbulb and bury it in a different location in the sandbox.


**6, 3 cm**

2)

When Sanne's dad returns with the watering-can, where will he give water to the flowerbulb? Draw a cross on that spot. You're allowed to draw only one cross.

Sample pages of the questionnaires (BRIEF and Vineland scales) addressed to teachers:

**BRIEF**

Student's Name ________________ Gender _____ Grade _____ Age_____ Birth Date ___/___/___
Your Name ________________ Today's Date ___/___/___
Relationship to Child: ☐ Teacher Class Taught __________ ☐ Counselor ☐ Other ________
How well do you know this student? ☐ Not well ☐ Moderately well ☐ Very well Have known student for ____ months

**N = Never S = Sometimes O = Often**

| | | | |
|---|---|---|---|
| 1. Overreacts to small problems | N | S | O |
| 2. When given three things to do, remembers only the first or last | N | S | O |
| 3. Is not a self-starter | N | S | O |
| 4. Cannot get a disappointment, scolding, or insult off his/her mind | N | S | O |
| 5. Resists or has trouble accepting a different way to solve a problem with schoolwork, friends, chores, etc. | N | S | O |
| 6. Becomes upset with new situations | N | S | O |
| 7. Has explosive, angry outbursts | N | S | O |
| 8. Has a short attention span | N | S | O |
| 9. Needs to be told "no" or "stop that" | N | S | O |
| 10. Needs to be told to begin a task even when willing | N | S | O |
| 11. Loses lunch box, lunch money, permission slips, homework, etc. | N | S | O |
| 12. Does not bring home homework, assignment sheets, materials, etc. | N | S | O |
| 13. Acts upset by a change in plans | N | S | O |
| 14. Is disturbed by change of teacher or class | N | S | O |
| 15. Does not check work for mistakes | N | S | O |
| 16. Cannot find clothes, glasses, shoes, toys, books, pencils, etc. | N | S | O |
| 17. Has good ideas but cannot get them on paper | N | S | O |
| 18. Has trouble concentrating on chores, schoolwork, etc. | N | S | O |
| 19. Does not show creativity in solving a problem | N | S | O |
| 20. Backpack is disorganized | N | S | O |
| 21. Is easily distracted by noises, activity, sights, etc. | N | S | O |
| 22. Makes careless errors | N | S | O |
| 23. Forgets to hand in homework, even when completed | N | S | O |
| 24. Resists change of routine, foods, places, etc. | N | S | O |
| 25. Has trouble with chores or tasks that have more than one step | N | S | O |
| 26. Has outbursts for little reason | N | S | O |
| 27. Mood changes frequently | N | S | O |
| 28. Needs help from adult to stay on task | N | S | O |
| 29. Gets caught up in details and misses the big picture | N | S | O |
| 30. Has trouble getting used to new situations (classes, groups, friends) | N | S | O |
| 31. Forgets what he/she was doing | N | S | O |
| 32. When sent to get something, forgets what he/she is supposed to get | N | S | O |
| 33. Is unaware of how his/her behavior affects or bothers others | N | S | O |
| 34. Has problems coming up with different ways of solving a problem | N | S | O |
| 35. Has good ideas but does not get job done (lacks follow-through) | N | S | O |
| 36. Leaves work incomplete | N | S | O |
| 37. Becomes overwhelmed by large assignments | N | S | O |
| 38. Does not think before doing | N | S | O |
| 39. Has trouble finishing tasks (chores, homework) | N | S | O |
| 40. Thinks too much about the same topic | N | S | O |
| 41. Underestimates time needed to finish tasks | N | S | O |
| 42. Interrupts others | N | S | O |
| 43. Is impulsive | N | S | O |

**Vineland**

## Communication Domain, continued

**Response Options:** **2** = Usually, **1** = Sometimes or Partially, **0** = Never

### Written Subdomain

The student does not need to have perfect spelling and sentence structure for a 2-point response on Written Subdomain items.

| Start Ages | | Item | Response | ✓ if Est. | Circle "?" If You Have a Question |
|---|---|---|---|---|---|
| Start Ages 3–7 | 1 | Identifies one or more alphabet letters as letters and distinguishes letters from numbers. (1) | 2 1 0 | ☐ | ? |
| | 2 | Identifies at least 10 printed letters of alphabet. (3) | 2 1 0 | ☐ | ? |
| | 3 | Shows understanding that written language is read in a particular direction (for example, from left to right in English; in some languages from right to left or top to bottom). | 2 1 0 | ☐ | ? |
| | 4 | Copies own first name. (5) | 2 1 0 | ☐ | ? |
| Start Ages 8–10 | 5 | Prints at least three simple words from example (for example, *cat, see, bee,* etc.). (7) | 2 1 0 | ☐ | ? |
| | 6 | Prints or writes own first and last name from memory. (8) | 2 1 0 | ☐ | ? |
| Start Ages 11–12 | 7 | Identifies all printed letters of alphabet, upper- and lowercase. (6) | 2 1 0 | ☐ | ? |
| | 8 | Reads at least 10 words aloud. (9) | 2 1 0 | ☐ | ? |
| Start Ages 13+ | 9 | Reads simple stories aloud (that is, stories with sentences of three to five words). (11) | 2 1 0 | ☐ | ? |
| | 10 | Prints at least 10 simple words from memory (for example, *hat, ball, the,* etc.). (10) | 2 1 0 | ☐ | ? |
| | 11 | Prints simple sentences of three or four words. (12) | 2 1 0 | ☐ | ? |
| | | **Ages 3–4 STOP. Ages 5+ continue.** | | | |
| | 12 | Reads and understands material of at least second-grade level. (14) | 2 1 0 | ☐ | ? |
| | 13 | Puts lists of words in alphabetical order. (15) | 2 1 0 | ☐ | ? |
| | 14 | Writes simple correspondence at least three sentences long (for example, postcards, thank-you notes, e-mail, etc.). (16) | 2 1 0 | ☐ | ? |
| | 15 | Demonstrates interest in both fact and fiction reading material. | 2 1 0 | ☐ | ? |
| | 16 | Uses print or electronic dictionary when needed. | 2 1 0 | ☐ | ? |
| | | **Age 5 STOP. Ages 6+ continue.** | | | |
| | 17 | Reads and understands material of at least fourth-grade level. (17) | 2 1 0 | ☐ | ? |
| | 18 | Writes reports, papers, or essays at least one page long; may use computer. (18) | 2 1 0 | ☐ | ? |
| | 19 | Edits or corrects own written work before turning it in (for example, checks punctuation, spelling, grammar, etc.). (21) | 2 1 0 | ☐ | ? |
| | 20 | Reads and understands material of at least sixth-grade level. (20) | 2 1 0 | ☐ | ? |
| | 21 | Plans, organizes, or outlines material to be written. | 2 1 0 | ☐ | ? |
| | 22 | Writes reports or compositions at least three pages long; may use computer. | 2 1 0 | ☐ | ? |
| | 23 | Reads and understands material of at least ninth-grade level. (23) | 2 1 0 | ☐ | ? |
| | 24 | Writes business letters (for example, requests information, makes complaint, or places order, etc.); may use computer. (25) | 2 1 0 | ☐ | ? |

*Comments or Observations:* ______________________________