

Social cognition and executive control in  
typical development and high-functioning  
autism spectrum disorder

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A thesis submitted for the degree of

**Doctor of Philosophy**

University College London

September 2015



## **DECLARATION**

I, Elif Gökçen, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.



## ABSTRACT

Social cognition and executive function are core components of adaptive social behaviour and follow a protracted developmental course. Importantly, deficits in both processes have been hypothesised to play causal role in the social difficulties characterising autism spectrum disorder (ASD). Despite substantial advances in the field, a number of important gaps have yet to be fully addressed. This thesis set out to empirically examine five outstanding research questions using data drawn from typically developing adults and adolescents, and a sample of adults diagnosed with high-functioning ASD.

Findings revealed evidence of age-related improvements in multiple domains of social cognition and executive control between middle adolescence and young adulthood (**Chapter 2**). Typically developing adults and adolescents with elevated autism symptomatology were found to display a qualitatively similar, though milder pattern of difficulties in facial affect processing, theory of mind, and executive control, and these impairments appeared to be independent of trait alexithymia (**Chapter 3**). Elevated levels of ASD traits were associated with difficulties in processing social information in the context of executive control, and, once again, these impairments were found to be independent of alexithymia (**Chapter 4**). Extending these measures to a clinical sample revealed ASD-specific impairments. Findings showed that compared to neurotypical controls, individuals with ASD were significantly poorer on a referential communication task performed under varying levels of cognitive load, and were less adept in regulating behavioural responses in the presence of affective information. ASD-related deficits were also observed on neutral measures of executive control. However, deficits on these tasks appeared to be less pronounced relative to a dual assessment task examining social and executive processing concurrently (**Chapter 5**). Finally, autism severity was associated with impaired perspective-taking abilities on a referential communication task. By contrast, no such associations were found between neutral measures of executive control. (**Chapter 5**)

Overall, findings from the current thesis contribute to a deeper understanding of the age-associated changes in social and executive function during the later stages of adolescence, and provide a more comprehensive understanding of ASD-related difficulties in higher-order cognition at the clinical and subclinical level.



## ACKNOWLEDGEMENTS

It would not have been possible to complete my PhD without the support and encouragement of the wonderful people around me.

First of all, I would like to thank my supervisors Dino Petrides and Norah Frederickson for their immense expertise and guidance throughout the entire PhD. In particular Dino for his constant encouragement, support, and generosity. Working with you has made me a more confident researcher and for that I am truly grateful. Norah for always being there with invaluable advice and for being incredibly generous with her time. It has been a true privilege to work with you both and I am already looking forward to our future collaborations.

I would also like to thank Luke Smillie for being an amazing undergraduate supervisor and mentor, and for inspiring me to study for a PhD. I owe you a pint or three when we eventually catch up!

A huge thanks to my fellow PhD students Lucy, Terry, Shiri, Kat, and Alex for being an incredible source of support over the past few years. Thanks also to Chloe, Pat, Lucy, Phil, Vanessa, and Liz for being the loveliest bunch of friends a stressed PhD student could ask for.

Finally, an extra special thanks to my wonderful mum and dad for their love, support, and unwavering belief in me. This thesis is dedicated to you!





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# 1 General Introduction

## 1.1 Preface

Humans are innately social creatures, deeply embedded in a world where social information is ubiquitous in everyday life. A key function of our cognitive apparatus is to facilitate the successful navigation of a varying and complex social terrain. This involves processing a continuous stream of socially relevant cues, combining this input with pre-existing knowledge about our own and others' beliefs, expectations, and desires, and using this information to generate adaptive and goal-directed responses. Performing these social computations in seamless fashion requires a number of complex abilities (e.g., maintaining attention, alternating between our own and others' perspectives, inhibiting inappropriate behaviours; Thornton & Conway, 2013; Ybarra & Winkielman, 2012), suggesting that along with social cognition, other higher-order processes, such as executive function, may be integral to successful communication and adaptive social behaviour.

A growing body of literature suggests that the frontal networks supporting social and executive processes follow a protracted course of maturation that extends into the third decade of life. In addition, disruptions in these higher-order abilities have been hypothesised to play a critical role in the social difficulties characterising Autism Spectrum Disorder. Although the past few decades have witnessed a considerable surge of interest in these processes, a number of important gaps have yet to be fully addressed.

Indeed, most developmental research examining social and executive processes highlight a prolonged developmental trajectory. Nonetheless, these investigations have mainly focused on younger adolescents, meaning that limited attention has been paid to the age-related changes in higher-order abilities between middle adolescence and young adulthood. In addition, autism research to date has primarily taken a dichotomous approach to the study of social cognition and executive control. Although these studies indicate a meaningful relationship between social and non-social processes, separate examination of these domains provide limited insight into how socio-affective information is processed in the context of executive control.

There is also an emerging corpus of research suggesting that typically developing individuals with elevated levels of ASD traits may be more susceptible than the general population to autism-related deficits. At present, however, research profiling social and executive processing at the subclinical level remains scarce, and

once again, very little is known about whether autism traits are associated with variability in processing of socially relevant cues in the context of executive control.

This thesis reports a series of studies that provide a detailed examination of social and executive processing in typical and atypical populations. A normative sample of adults and adolescents were recruited to assess whether higher-order cognitive abilities continued to advance between the mid-to-later stages of adolescence and young adulthood. This thesis also examined whether typically developing participants with elevated levels of autism symptomatology would demonstrate poorer performance on separate and concurrent measures of social and non-social information processing. Furthermore, this line of inquiry was extended to a sample of adults diagnosed high-functioning with ASD in order to examine whether performance deficits on combined paradigms were more pronounced relative to tasks assessing executive control in the absence of socially-relevant stimuli. A final aim was to determine whether performance on combined and neutral paradigms were related to diagnostic severity in adults with ASD.

The present introductory chapter provides a review of the existing literature surrounding social and executive processes that are suggested to underpin optimal social behaviour. The development of social cognition and executive control in neurotypical adolescents and adults will be reviewed first. This chapter then presents a review of social cognition and executive control literature relating to ASD, including a discussion of subclinical autism traits and the potential influence of co-morbid alexithymia. Associations between higher-order cognition and autism severity as indexed by the Autism Diagnostic Observation Schedule (ADOS; Lord, Luyster, Gotham, & Guthrie, 2012; Lord, Rutter, et al., 2012) will also be reviewed. Last, a summary of extant literature on social and executive processing in typical development and ASD is presented, and five outstanding research questions are highlighted.

## **1.2 Introduction to Adolescence**

### *1.2.1 Overview*

Adolescence is a developmental period characterised by immense changes in physical, social, and cognitive development (Crone & Dahl, 2012; Ernst et al., 2006; Patton & Viner, 2007; Spear, 2000). This transition from childhood to adulthood is

also characterised by an increased salience of peer influence, and represents a period of heightened vulnerability to risk-taking and injurious behaviour (e.g., binge-drinking, drug use, criminal activity, and unprotected sex; Casey & Jones, 2010; Dahl, 2004; Steinberg, 2007; 2008). These risk factors are particularly prominent during mid-to late adolescence (Crone & Dahl, 2012; Steinberg, 2008), suggesting that socio-emotional and cognitive development extends across adolescence and continues into adulthood (Apperly, Samson, & Humphreys, 2009; Steinberg, 2008).

The successful completion of adolescence is defined by autonomous behaviour, adaptive decision-making skills, and the ability to effectively navigate complex social terrain (Blakemore & Mills, 2014). Studies have shown that the neural mechanisms underpinning these skills undergo profound maturation during adolescence (Steinberg, 2005). Specifically, the prefrontal regions supporting higher-order cognitive processing follow a gradual and protracted course of development, starting from preadolescence and continuing through to early adulthood (Arian et al., 2013; Casey, Getz, & Galvan, 2008; Giedd, 2008; Giedd Blumenthal, Jeffries, Castellanos, Liu, Zijdenbos, et al., 1999; Gogtay, Giedd, Lusk, Hayashi, Greenstein, Valtuzis, et al., 2004; Johnson, Blum, & Giedd, 2009). Neural rewiring during the mid- to late adolescence period involves age-dependent modifications in white matter volume and synaptic refinement, a process which is thought to facilitate functional connectivity between brain regions (Blakemore & Choudhury, 2006; Geidd et al., 1999; Gogtay et al., 2004; Paus, 2005; Sowell, Peterson, Thompson, Welcome, Henkenius, Toga, et al., 2003). Consequently, maturation of the frontal regions may serve to enhance the neural circuits relevant for higher-level cognitive skills, such as executive function and social cognition (Blakemore & Choudhury, 2006).

### **1.3 Higher-Order Processing in Adolescence**

#### *1.3.1 Executive Function*

Executive function, the cognitive mechanisms underpinning adaptive and goal-directed behaviour, is thought to be mediated by the prefrontal cortex (Selemon, 2013). This umbrella term captures a series of distinct, yet interrelated processes, including planning, cognitive flexibility (or set-shifting), working memory, and response inhibition (Miyake et al., 2000; Stuss & Knight, 2002). These functions are critical in

everyday life, as they allow one to monitor and regulate ongoing behaviour in line with changing contextual demands in a variety of social, emotional, and cognitive situations (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Gyurak, Goodkind, Madan, Kramer, Miller, & Levenson, 2009; Lezak, 1995; Lezak, Howieson, Loring, Hannay, & Fischer, 2004). More generally, executive function has been linked to physical and mental wellbeing, as well as academic success and positive life outcomes (Bull, Espy, & Wiebe, 2008; Diamond, 2013). In addition, aberrant executive processing is thought to underlie a variety of psychiatric and neurodevelopmental disorders, such as ASD, ADHD, schizophrenia, Tourette's syndrome, and obsessive-compulsive disorders (Green, Penn, Bentall, Carpenter, Gaebel, Gur 2008; Hill, 2004; Russell, 1997).

### *1.3.1.1 Development of executive function*

Data from behavioural and neurophysiological investigations suggest that executive processing continues to develop during adolescence and early adulthood. Findings from these studies reveal age-related improvements on tasks assessing response inhibition (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Tamm, Menon, & Reiss, 2002), cognitive flexibility (Huizinga, Dolan, & Van der Molen, 2006), working memory (Anderson, Anderson, et al, 2001), and planning performance (Albert & Steinberg, 2011; De Luca et al., 2003; Huizinga, et al., 2006; Luciana, Collins, Olson, & Schissel, 2009; Guevera, Martinez, Aguirre, & Gonzalez, 2012; but see Anderson et al., 2001). Furthermore, neuroimaging research indicates that these changes in executive control abilities mirror the time course of prefrontal cortex maturation (Casey et al, 1997; Gaillard et al, 2000; Tamm et al, 2002).

However, while these findings support the notion of age-related linear increases in executive processing, there have been some discrepancies within the literature. For instance, data from a recent behavioural investigation suggests a non-linear course of development for executive control. Using a wide battery of tasks, Taylor and colleagues (Taylor, Barker, Reidy, & McHale, 2013) assessed multiple aspects of higher-order processing across three age groups (17, 18, and 19 year olds). Analysis revealed better strategy generation for 17 year olds relative to 18 and 19 year olds, and better concept formation in 17 year olds in comparison to 18 year olds. No age-related differences were found on tasks assessing response inhibition, planning ability, and

rule detection. Based on these data, the authors propose that the nonlinear pattern of performance may reflect developmental changes in regions supporting selective domains of executive control. These results also appear consistent with the suggestion that different executive skills progress at different rates, follow diverse developmental trajectories, and reach maturity at different stages of development (Blakemore & Choudhury, 2006; Huizinga et al., 2006; Romine & Reynolds, 2005).

Taken together, studies examining executive function in adolescence primarily yield support for a protracted and linear course of development, which appears to continue through to the early stages of adulthood. Consequently, these findings appear to corroborate the suggestion that age-associated improvements in executive function reflect a fine-tuning of the frontal networks supporting higher-level cognitive processing (Casey et al., 1997; Gaillard et al., 2000; Tamm et al., 2002).

### *1.3.2 Social Cognition*

Along with executive function, development of the prefrontal cortex is also thought to play an important role in certain domains of social cognition. Defined broadly, social cognition refers to our ability to make sense of the world through processing complex interpersonal cues generated by conspecifics (Frith, 2008). Social cognitive processes typically include emotion identification, resonating with others affective experiences, and the ability to understand and evaluate our own and others behaviour in terms of underlying mental states (also referred to as mentalising, cognitive empathy, perspective-taking, or theory of mind [ToM]; Baron-Cohen, et al., 1985; Frith, 2001; Frith & Frith, 1999; 2007; Premack & Woodruff, 1978). These processes are fundamental to the successful navigation of one's social world and the regulation of interpersonal behaviour in a skilful and adaptive manner (Adolphs, 2003). Moreover, similar to executive impairments, atypicalities in social cognitive processes have consistently been implicated in a wide range of psychological disorders (e.g., ASD, depression, schizophrenia, and eating disorders, Pellicano et al., 2007; Green et al., 2008; Hill, 2004; Russell, 1997; Russell Schmidt, Doherty, Young, & Tchanturia, 2009), and have also been associated with long-term negative outcomes, such as social isolation and mental health difficulties (Bellini, 2006; Orsmond et al., 2013; Shattuck, Orsmond, Wagner, & Cooper, 2011).

Deficits in social cognition have been associated with long-term negative outcomes, such as psychological distress, social isolation, and mental health problems



(Bellini, 2006; Orsmond, Shattuck, Cooper, Sterzing, & Anderson, 2013; Shattuck, Orsmond, Wagner, & Cooper, 2011), and, similar to executive impairments, have consistently been implicated in a wide range of psychological disorders (e.g., ASD, depression, schizophrenia, and eating disorders; Pellicano et al., 2007; Green et al., 2008; Hill, 2004; Russell, 1997; Russell Schmidt, Doherty, Young, & Tchanturia, 2009).

#### *1.3.2.1 Development of Social Cognition*

For many years, it was thought that social cognitive abilities were largely established by the age of six or seven (Mills, Lalonde, Clasen, Giedd, & Blakemore., 2014; Wimmer and Perner, 1983). However, findings from more recent investigations demonstrate that social cognition advances beyond childhood and adolescence (Dumontheil, Apperly, & Blakemore, 2010; Thomas, De Bellis, Graham, & LaBar, 2007). In line with these data, neuroimaging studies suggest that brain regions involved in social cognition undergo a prolonged course of development that extends well into the second decade of life, and continues through to early adulthood (Blakemore, 2008). Remodelling of the prefrontal cortex during adolescence is thought to have a profound impact on higher order social-cognitive processes, such as mentalising ability and facial emotion processing (Blakemore & Choudhury, 2006; Choudhury, Blakemore, & Charman, 2006).

#### *1.3.2.2 Theory of Mind*

Imaging studies have consistently linked ToM abilities to prefrontal networks (e.g., medial prefrontal cortex [PFC], ventral medial PFC, dorsolateral PFC), as well as to posterior brain regions, such as the posterior cingulate cortex/precuneus, temporo-parietal junction (TPJ), superior temporal sulci (STS), temporal poles, and amygdala (Blakemore, 2008; Castelli, Happé, Frith, & Frith, 2000; Frith & Frith, 2003; Gallagher & Frith, 2003; Saxe, 2006; Saxe & Kanwisher, 2003). In addition, lesion studies have also associated the frontal cortex, STS, and TPJ in mentalising ability (Apperly et al., 2005; Happé, Malhi, & Checkly, 2001).

A number of fMRI studies investigating ToM development during adolescence report a decline in medial PFC activity between adolescence and adulthood. For instance, Wang and colleagues (Wang, Lee, Sigman, & Dapretto, 2006), found that children and young adolescents (9-14) recruited the mPFC more strongly than adults (23-33) on a task assessing irony comprehension. Similarly, another fMRI study

examining intentional causality (Blakemore, den Ouden, Choudhury, & Frith, 2007) also reported greater dorsal mPFC activation in adolescents (aged 12-18) in comparison to adults (aged 22-38). A more recent study investigating the neural correlates of ToM (Moor, Macks, Guroglu, Rombouts, Molen, & Crone, 2012) administered the 'Reading the Mind in the Eyes Test' (Baron-Cohen et al., 2001) to a group of early adolescents (aged 10-12), mid adolescents (14-16), and young adults (aged 19-23). Findings showed that whilst younger adolescents activated the ventral mPFC when attributing mental states to pictures of eyes, this region was not engaged in the mid adolescent or young adult groups.

There are many plausible explanations for the age-related changes in frontal activity during mental state reasoning. One possibility is that adults and adolescents may employ different neurocognitive strategies when performing mentalising tasks. A further possibility is that age-related variations in functional recruitment reflect the maturational processes (e.g., synaptic pruning) involved in reorganising and fine-tuning prefrontal circuits (Blakemore, 2008).

Development of mentalising ability during adolescence has also been studied at the behavioural level. For instance, using an adapted version of the Director Task, Dumontheil and colleagues (Dumontheil, Apperly, & Blakemore, 2010) examined online ToM use across five age groups: Child I (aged 7.3-9.7), Child II (9.8-11.4); Adolescent I (11.5-13.9 years); Adolescent II (14-17.7 years), and Adults (19.1-27.5 years). Participants were presented with a set of shelves containing several objects, which they are instructed to move by a "Director," who could only see some of the objects. During the critical trials, participants were required to use information about the director's visual perspective in order to select the correct object from the shelves. The Director Task differs from other ToM measures in that successful performance involves both intact mentalising (e.g., taking another person's perspective) and executive processing (e.g., inhibiting egocentric bias, and making quick and accurate response selections).

Findings showed that performance in the director and control conditions improved between Child I and Adolescent II. However, while the Adolescent II and Adult groups demonstrated similar accuracy levels on the control trials, the Adolescent II group made more errors than the adults in the director condition. These data suggest that ToM use, and the interaction between ToM and executive control is still undergoing maturation across the later stages of adolescence and adulthood

(Dumontheil et al., 2010). Furthermore, these results appear consistent with imaging studies demonstrating that brain regions associated with mental-state reasoning undergo a protracted course of development, both structurally and functionally during adolescence (Giedd et al., 1999; Mills et al., 2014; for a review, see Blakemore, 2008 and Blakemore & Mills, 2014).

Despite these findings, however, some studies have failed to document age-related improvements in ToM ability beyond mid-adolescence. For example, while Bosco and colleagues (Bosco, Gabbatore, & Tirassa, 2014) reported linear increases in mentalising performance between the ages of 11 and 15, no further improvements were observed between 15 and 17 years. Similarly, Taylor et al., (2013) found comparable levels of mentalising ability among 17, 18, and 19 year olds on a series of tasks assessing static (e.g., images) and naturalistic (e.g., video clips) ToM. In light of these data, the authors suggest that ToM development plateaus between 15 and 17 years, and remains relatively stable across the later stages of adolescence.

#### *1.3.2.3 Affective Empathy*

The affective component of empathy involves resonating with others' feelings, whilst understanding that they are different from our own emotional state (de Vignemont & Singer, 2006; Shamay-Tsoory, 2011; Shamay-Tsoory, Aharon-Peretz, & Perry, 2009). Although, mentalisation and affective resonance are related processes, they are thought to reflect discrete forms of empathy, drawing upon interacting, yet partially distinct neural circuits (Decety, 2011; Decety & Michalska, 2010; Nummenmaa, Hirvonen, Parkkola, & Hietanen, 2008). To date, the ability to resonate with others' emotional experiences has frequently been associated with the anterior insula, amygdala, hypothalamus, orbitofrontal cortex, IFG, and the anterior and dorsal mid-cingulate cortex (Decety, 2011; Fan et al., 2011; Lamm, Decety, & Singer, 2011; Nummenmaa, et al., 2008; Walter, 2012).

With respect to developmental time course, the ability to resonate with others' emotional experiences is thought to emerge much earlier than ToM. For instance, studies have found that newborns (Dondi, Simion, Carlton, 1999; Martin & Clark, 1987) and older infants (Geangu, Benga, Stahl, & Striano, 2010) display increased signs of distress when presented with the sound of another infant crying. In contrast, more PFC-dependent functions, such as ToM, follow an extremely protracted course

of development, with age-associated improvements continuing into the early stages of adulthood (e.g., Dumontheil et al., 2010).

#### *1.3.2.4 Facial Affect Processing*

Processing facial displays of emotion has frequently been associated with prefrontal circuits, as well as the fusiform gyrus, insula, and amygdala (Fusar-Poli, Placentino, Carletti, Landi, Allen, et al., 2009; Haxby, Hoffman, & Gobbini, 2000; Thomas, De Belis, Graham, & LaBar, 2007; Winston, O'Doherty, & Dolan, 2003).

To date, behavioural data have shown continuing development of facial affect recognition during adolescence (see Blakemore, 2008 for a review). For example, an earlier study, in which adolescents (aged 10-17 years) matched facial expressions to emotion descriptors, reported a non-linear pattern of development for emotion recognition (McGivern, Andersen, Byrd, Mutter, & Reilly, 2002). Findings revealed a brief regression in emotion recognition abilities at the onset of puberty (10-11 year-old girls and 11-12 year-old boys). Performance was then found to gradually improve over the following 2-3 years, and stabilise around 16-17 years of age.

Another study by Thomas and colleagues (2007) investigated emotion identification using images of morphed faces that ranged along three continua from neutral to anger, neutral to fear, and fear to anger (Thomas et al., 2007). Participants included older children (7-13 years), adolescents (14-18 years), and adults (25-57 years). Findings showed that across all emotion morphs, adults were more accurate in identifying subtle changes in expression intensity in comparison to children and adolescents. Furthermore, analysis revealed different developmental trajectories for fear and anger recognition. Whilst, sensitivity to fear expressions increased linearly across all three age groups, sensitivity to anger displayed a quadratic trend, with accuracy improving rapidly between adolescence and adulthood. Consequently, these findings indicate continuing improvement of facial affect processing during adolescence, and also suggest that fear and anger recognition may rely on distinct neural correlates that mature at different rates between adolescence and adulthood (Thomas et al., 2007).

Indeed, this interpretation fits in with the imaging data showing different neural substrates for emotional expressions of fear and anger. For instance, whilst amygdala activation has been reported for a range of basic emotions (Fitzgerald, Angstadt, Jelsone, Nathan, & Phan, 2006; Winston et al., 2003; Yang et al., 2002),

some studies have shown increased activation in response to images depicting fearful faces (Breiter, Etcoff, Whalen, Kennedy, Rauch, Buckner, et al., 1996; Fusar-Poli, et al., 2009; Morris, Frith, Perrett, Rowland, Young, Calder, & Dolan, 1996; 1998; Whalen, Shin, McInerney, Fisher, Wright, & Rauch, 2001). Similarly, despite being implicated in emotion processing more generally, greater PFC activation has been documented for facial expressions of anger (Blair, Morris, Frith, Perret, & Dolan, 1999). In addition, the finding that anger recognition develops later than fear recognition is also consistent with studies reporting later development of prefrontal regions (Giedd et al., 1999; Gogtay et al., 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999), in comparison to the amygdala (Giedd, Snell, Lange, Rajapakse, Casey, Kozuch, et al., 1996; Schumann, Hamstra, Goodlin-Jones, Lotspeich, Kwon, Buonocore, et al., 2004). Nonetheless, whilst these regions demonstrate some level of emotion specificity (Fusar-Poli, et al., 2009; Phan, Wager, Taylor, & Liberzon, 2002), evidence from some neurophysiological studies suggest that emotion categories have wider and overlapping neural representations in the brain (Fusar-Poli, et al., 2009; Phan, Wager, Taylor, & Liberzon, 2002).

Evidence from fMRI studies also suggest continuing development of the brain regions supporting facial affect processing during adolescence. For instance, Yurgelun-Todd and Killgore (2006) reported increased frontal activity in response to images depicting facial expressions of fear in participants aged between 8 and 15 years. Likewise, another fMRI study by Guyer and colleagues (Guyer, Monk, McCure-Tone, Nelson, Roberson-Nay, Adler, et al., 2008) revealed greater amygdala activation to fearful faces in adolescents (aged 9-17 years) than in adults (aged 21-40 years). An earlier study assessing developmental differences in brain activity during selective attention to emotional stimuli found a similar pattern of results (Monk et al., 2003). Findings showed that when passively viewing images of fearful relative to neutral expressions, adolescents (aged 9-17 years) exhibited greater amygdala, anterior cingulate cortex, and orbitofrontal cortex activation relative to adults (aged 25-36 years). Furthermore, in comparison to adults, adolescents displayed higher ACC activation when attention was switched to a non-emotional feature of facial expressions (i.e., nose-width). Consequently, these findings suggest an age-related decrease in frontal activity and also appear consistent with behavioural data reporting a linear trajectory for fear recognition (Thomas et al., 2007). Findings also showed that whilst adults modulate brain activity based on attentional demands, adolescents

modulate activity based on the emotional relevance of a stimulus. This suggests that the ability to modulate attention in the presence of emotionally salient information is still undergoing maturation between adolescence and adulthood.

Overall, the behavioural and neuroimaging studies reviewed above highlight two key findings: (i) mentalising ability and facial affect recognition follow a protracted course of development, and (ii) frontal activity during social-emotion processing decreases between adolescence and adulthood. Taken together, these data appear consistent with the notion that age-related improvements in social cognition may parallel a fine-tuning of the neural circuits underpinning higher-order cognitive processing (Casey et al., 1997; Casey et al., 2008).

## **1.4 Introduction to Autism Spectrum Disorder**

### *1.4.1 Overview of ASDs*

Numerous investigations have reported atypicalities in social cognition and executive control in Autism, a life-long neurodevelopmental disorder marked by profound impairments in social communication and social interaction, as well as repetitive behaviours and restricted interests (American Psychiatric Association, 2013).

Recent studies have found that approximately 1.1% of the UK population are diagnosed with an ASD, with the condition being more frequent in males than in females (Baird, Simonoff, Pickles, Chandler, Loucas, et al. 2006; Brugha, Cooper, McManus, et al. 2012; Brugha, McManus, Meltzer, et al. 2009). Due to the absence of clear biological markers for autism, current diagnosis is solely based on behavioural criteria (Lord, Risi, Lambrecht Cook, Leventhal et al., 2000).

Autism is an umbrella term used to describe a group of closely related conditions, referred to as Autism spectrum disorders (ASD), and typically comprises autistic disorder (AD), high functioning autism (HFA), Asperger syndrome (AS) and pervasive developmental disorder not otherwise specified (PDD-NOS). While all individuals with autism share certain core difficulties, there is a wide degree of variation in symptom severity. For instance, many individuals diagnosed with AD suffer from severe learning difficulties (e.g., IQ below 70) and generally require a lifetime of specialist support, whereas individuals with HFA, AS, and PDD-NOS

usually have normal or above average IQs, and may be able to live a relatively independent life.

Importantly, studies have suggested that features of autism extend beyond the clinical boundaries of the disorder. Recent family studies have shown that non-autistic relatives may carry a genetic liability that results in the expression of the broader autism phenotype (BAP), which is a term used to describe a set of ‘sub-clinical’ traits that are milder, but qualitatively similar to the social, cognitive, and language difficulties associated with ASDs (Baron-Cohen et al., 2001; Constantino et al., 2006). Further, in more recent years, the continuum view of ASDs has proposed that all individuals vary along a dimension of social communication skills, ranging from typical development, through to HFA and AS, and with AD at the most severe end of the spectrum (Baron-Cohen et al., 2001; Hoekstra, Bartles, Cath & Boomsma, 2008). Collectively, these studies indicate that there is a strong genetic component to ASDs and that the expression of sub-threshold ASD traits may go beyond non-autistic relatives, and extend into the general population.

One of the most striking features of autism is within the realm of social behaviour. ASDs are characterised by marked difficulties in social functioning, such as independent living, employment, and interpersonal relationships. Consequently, impairments in these areas prevent the individual from leading a ‘normal’ life and further, may result in long-term negative effects in a range of domains, such as psychological distress, social isolation, and mental health difficulties (Bellini, 2006; Orsmond et al, 2013; Shattuck et al., 2013) . Compared to those with AD, individuals with AS and HFA could be at a greater risk of developing psychological disorders (e.g., anxiety and depression), as their motivation to form friendships (Klin, Pauls, Schultz, & Volkmar, 2005), and intact cognitive abilities may provide a certain degree of insight into social difficulties (Frith, 2004).

A large body of research has been dedicated to understanding the underlying mechanisms of social dysfunction in ASDs. While these studies have proposed that an association between social cognition and executive function may explain atypicalities in social behaviour, results have been somewhat inconsistent. Understanding the neuro-cognitive underpinnings of impaired psychosocial functioning is imperative to advancing our knowledge of the disorder, and essential to better inform intervention programmes aiming to improve positive life outcomes for individuals with ASDs.

## **1.5 Higher-order Cognition in ASD**

### *1.5.1 Social Cognition*

As mentioned earlier in this chapter, social cognition refers to a set of mental operations (e.g., the ability to process social information, recognise others, and evaluate our own and others' mental states, feelings and actions), that are required successfully to navigate one's social world and regulate interpersonal behaviour in an adaptive manner (Adolphs, 2003, 2009; Brothers, 1990; Frith, 2007; Frith & Frith, 2003; Green, et al., 2008). Indeed, impairments in these processes are likely to result in significant interpersonal difficulties and negatively impact quality of life. Although numerous components of social cognition have been examined in relation to ASD, two in particular have received considerable attention: facial affect recognition and empathic functioning. These processes are reviewed in detail below.

#### *1.5.1.1 Facial Affect Recognition*

The human face is a highly salient and complex form of visual stimulus that provides a wealth of information (e.g., identity, mood, intentions, and gaze direction), critical for interpersonal communication and adaptive social behaviour (Ellis & Young, 1998; Cohen Kadosh & Johnson, 2007; Frischen, Bayliss & Tipper, 2007). Accurate perception of facial cues allows one to connect with others, and it has been argued that the ability to recognise basic emotional expressions may be universal and biologically innate (Darwin, 1872; Ekman, 2003). However, others contend that rather than being biologically ingrained, our perception and interpretation of emotion is conscious and characterised along two dimensions: hedonic valence and arousal (see Russell & Barrett, 1999 for further discussion).

The capacity to recognise and respond to facial expressions of basic emotion is central to social understanding and serves as a vital building block for the development of more sophisticated social cognitive processes, such as mentalising and empathy. Whilst this line of research has received considerable attention in autism research, the current literature on facial affect processing has yielded a mixed pattern of results, with some studies reporting atypicalities in the detection of basic emotions (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Hobson, Ouston, & Lee, 1988; Rogers, Viding, Blair, et al., 2006; Rump, Giovannelli, Minshew, & Strauss, 2009), with specific impairments in processing negative affect (Ashwin et al., 2006; Ellis &



Leafhead, 1996; Golan & Baron-Cohen, 2006; Howard Cowell, Boucher, Broks, Mayes, Farrant, & Roberts, 2000), others document spared abilities (Adolphs, Sears, & Piven, 2001; Balconi & Carrera, 2007; Castelli, 2005; Tracy, Robins Schriber, & Solomon, 2011).

The following section provides an overview of ASD-related affect recognition literature and highlights key methodological issues which may account for the mixed pattern of results.

To date, numerous empirical studies have revealed atypical emotion recognition in ASDs in a range of studies, such as matching facial expressions of emotion (Hobson et al., 1988; Braverman, Fein, Lucci & Waterhouse, 1989), and finding the 'odd one out' from an array of affective facial stimuli (Tantam, Monaghan, Nicholson & Stirling, 1989). Nevertheless, the most commonly used test in this line of research involves decoding facial expressions from static images portraying the six 'basic' emotions (i.e. anger, disgust, fear, happiness, sadness, and surprise), in a forced-choice paradigm (Ekman & Friesen, 1976). Several studies employing this test have thus far reported ASD-related impairments in basic emotion processing (Ashwin et al., 2006; Celani, Battacchi, & Arciacono, 1999; Davies, Bishop, Manstead, & Tantam, 1994; Eack, Mazefsky, & Minshew, 2014; Wallace, Coleman, & Bailey, 2008). However, other studies have reported no significant differences between ASD and typically developing populations (Adolphs Sears, & Piven, 2001; Baron-Cohen, Wheelwright, & Joliffe, 1997; Castelli, 2005; Ozonoff, Pennington, & Rogers, 1990; Jones, Pickles, Falcaro, Marsden, Happé, Scott, Sauter et al., 2011).

Additionally, a number of studies have reported specific, rather than global, deficits in basic emotion recognition. For instance, some have found evidence showing that individuals with ASDs have difficulties in identifying particular negative emotions, such as fear (Howard et al, 2000), and disgust (Golan & Baron-Cohen, 2006), whilst others report deficits for multiple negative emotions (e.g., sadness, anger, fear, and disgust; Ashwin et al., 2006; Ellis & Leafhead, 1996).

In contrast to these findings, some studies only report ASD-related impairments in the recognition of belief-based emotions, such as surprise (Adolphs et al., 2001; Baron-Cohen, Spitz, & Cross, 1993; Baron-Cohen et al., 2001; Golan et al., 2006). Surprise is believed to involve more cognitive processing relative to other basic emotions, as it requires the ability to accurately infer that the individual is faced with an unexpected situation (Baron-Cohen et al., 1993). Consequently, these studies have

led to the assumption that individuals with ASDs experience difficulties in the processing of more complex emotions from facial expressions, rather than basic emotions.

Taken together, these investigations have yielded a mixed pattern of findings in relation to emotion processing in ASDs. There are a number of possible explanation for the divergent results. For instance, the wide age ranges of the ASD groups under study may give rise to inconsistent patterns of data. There is also great variation in relation to ability, with studies recruiting individuals from across the autism spectrum (e.g., high or low functioning), and also in the criteria used to match ASD and typically developing groups (e.g., verbal IQ vs. total IQ). For example, while studies matching groups based on total IQ document atypical basic emotion processing (Aswin et al., 2006; Braverman et al., 1989; Tantam et al., 1989), those that matched according to verbal IQ found no significant group differences (Castelli, 2005; Davies, Bishop, Manstead, & Tantam, 1994; Ozonoff et al., 1990).

The variation in experimental procedures may also explain the mixed evidence regarding emotion recognition abilities in ASDs. For example, a large number of studies have used static (i.e., photographs of faces depicting expressions at full intensity), rather than dynamic (e.g., video clips of animated faces) stimuli. However, unlike video clips, static images fail to capture the intricate nature of real-life facial expressions experienced in everyday social encounters, and are therefore deemed to lack ecological validity. Furthermore, the simplicity of posed photographs could have led to ceiling effects and may also explain why some individuals with ASD display typical emotion processing abilities in lab-based settings, but experience clear deficits in daily social interactions.

Consistent with this view, impaired processing of dynamic facial expressions has been demonstrated in various empirical investigations. For instance, studies using the morphing faces paradigm report that individuals with ASDs are less proficient at emotion recognition than typically developing peers. The morphing faces task (MFT) typically requires participants to identify basic emotions from images or video clips of facial expressions that are incrementally morphed through various stages of intensity (i.e., ranging from neutral to full emotional expression). Using this procedure Law Smith, Montagne, Perrett, Gill, & Gallagher (2010) documented significant group differences in the recognition of emotional stimuli. When facial expressions were presented at lower intensities, individuals with HFA were less accurate in processing

anger, surprise, and disgust, compared to age and IQ matched-controls. However, when stimuli were presented at full (100%) intensity, processing deficits only emerged for facial expressions of disgust. Wallace, Case, Harms, Silvers, Kenworthy & Martin (2011) revealed a similar pattern of results using a variant of the MFT in a sample of adolescents with and without ASD. Findings showed that those diagnosed with HFA were less accurate in identifying emotional expressions, when compared to matched controls. In particular, the HFA group demonstrated reduced sensitivity to dynamic facial expressions of sadness, and required higher levels of intensity in order to correctly identify stimuli from this emotion category. Importantly, impaired sadness recognition was uniquely related to lower social functioning and higher ratings of ASD symptomatology. These findings suggest that difficulties in processing affective information may negatively impact communicative performance, as they are likely to hinder the ability generate appropriate responses to others emotional states.

Real-world social interactions require one to read and identify emotional expressions of varying intensities (De Sonnevile, Verschoor, Njikiktjien, Op het Veld, Toorenaar, & Vranken, 2002). Thus, while processing high-intensity emotions may be intact in those with ASDs, the inability to rapidly and accurately decode another person's emotional state from subtle expressions is likely to impede adaptive social behaviour, and may provide insight into the empathy and mentalising deficits characterising the disorder.

#### *1.5.1.2 Empathic Processing*

Empathy, the ability to understand, experience, and respond to the emotional state of another person, is integral to successful human relationships (Decety & Jackson, 2006; Dziobek, Rogers, Fleck et al., 2008; Rameson, Morelli, & Lieberman, 2012; Singer, 2006). Although there is a notable lack of consensus regarding the definition, most researchers agree that empathy is a multifaceted construct comprising two distinct, but related components: affective and cognitive empathy. As highlighted in the previous section, the affective component involves the capacity to resonate with another person's emotional state, while the cognitive component (also referred to as mentalizing, or theory of mind; ToM), involves the ability to predict and understand another person's thoughts, feelings, and intentions, without becoming emotionally

involved (Premack & Woodruff, 1978; Shamay-Tsoory, 2011; Shamay-Tsoory, Aharon-Peretz, & Perry, 2009).

Aberrant empathic functioning is one of the key features of ASDs (Baron-Cohen et al., 1985; Baron-Cohen & Wheelwright, 2004; Dziobek et al., 2008; Gillberg, 1992; Wing, 1981), and there is a large amount of empirical evidence documenting dissociable deficits in relation to this construct (Dziobek et al., 2008; Jones, Happé, Gilbert, Burnett, & Viding, 2010; Shamay-Tsoory et al., 2009). While ASD has been associated with profound impairments in cognitive empathy, findings suggest that affective empathy is largely spared. For instance, Baron-Cohen and Wheelwright (2004) document lower levels of empathy for adults with ASDs using the empathy quotient (EQ), a 40-item self-report questionnaire that primarily focuses on cognitive empathy. In a later investigation, Rogers et al., (2007) administered a multidimensional measure of empathy, the Interpersonal Reactivity Index (IRI; Davis, 1980), to a group of adults with AS. Findings revealed that the AS group scored lower than typically developing controls on measures of cognitive empathy, such as perspective taking and fantasy (the tendency to resonate with fictional characters). However, there were no significant group differences on measures of affective empathy (e.g., empathic concern). In fact, the AS group obtained higher scores than controls on a second measure of affective empathy (the personal distress subscale). Consequently, these findings suggest that although individuals with AS have difficulties in ToM, they are able to experience as much care and concern for other people as typically developing individuals do.

Similar deficits have been reported using behavioural measures of ToM, such as the reading the mind from the eyes test (RMET; Baron-Cohen et al., 2001; Baron-Cohen, Wheelwright, & Jolliffe, 1997). The RMET requires participants to view photographs of the eye region of the face and decode complex mental states (e.g., pensive, contemplative, flirtatious, & quizzical), based on this information only. Participants select one of four descriptors to identify what the person is thinking or feeling, and the proportion of correct responses serves as the index of performance. In line with prior self-report investigations, studies using the RMET have shown greater ToM impairment for individuals with ASDs relative to neurotypical controls (Baron-Cohen et al., 2001; Baron-Cohen et al., 1997; Baron-Cohen, Wheelwright, Scahill, Spong, & Lawson, 2001b; Dziobek et al., 2006; Lahera et al., 2014).

Another example of an advanced ToM task is the Strange Stories test (SS; Happé, 1994), which consists of 24 short stories about social situations involving jokes, lies, white lies, misunderstandings, bluffing, irony, or sarcasm. This task requires participants to read vignettes and explain why the character says something that they do not literally mean. Each story is accompanied by a picture and two test questions relating to comprehension (“Was it true, what X said?”) and mental state justification (“Why did X say that?”). Successful performance on the Strange Stories entails the ability to accurately ascribe complex mental states such as desires, beliefs or intentions, in addition to making higher order inferences (e.g., one character’s belief about what another character knows). The Strange Stories has revealed significant mind-reading difficulties in high functioning adults and children with ASD, relative to typically developing controls (Happé, 1994; Jolliffe & Baron-Cohen, 1999; Kaland, Moller-Nielsen, Callesen, Mortensen, Gottlieb & Smith, 2002; Kaland, Moller-Nielsen, Smith, Mortensen, Callesen, & Gottlieb, 2005).

However, in contrast to the abovementioned studies, some researchers have found no group differences on the Strange Stories test, suggesting comparable mindreading abilities for individuals with and without ASDs (Ponnet, Roeyers, Buysse, De Clercq, & Van Der Heyden, 2004; Roeyers, Buysse, Ponnet, & Pichal, 2001). Taken together, results from traditional measures of ToM provide a somewhat inconsistent picture. Such discrepancies may be attributed to differences in the sample characteristics, such as cognitive ability. For example, participants in the Roeyers et al., (2001) study had slightly higher average IQ’s (mean IQ 113) relative to participants in other studies (mean IQs ranging from 96 -107). Another potential explanation is that these tasks lack ecological validity. Many self-report and laboratory-based ToM tasks do not reflect the intricate nature of everyday interactions, and may consequently fail to capture the subtle communication deficits impeding adaptive social behaviour. For instance, while the RMET involves decoding mental states from static images of the eye region, real-life social encounters require an individual to process social cues from various modalities (e.g., facial expression, gaze direction, tone of voice, and posture). Thus, the demands of naturalistic social situations are expected to outweigh that of social cognition tasks comprising still images.

Unlike traditional ToM tasks, video formats incorporating both verbal and non-verbal stimuli provide a closer approximation of everyday social contexts and may be

more sensitive to identifying subtle impairments in mind-reading. To date, only few dynamic tasks have examined ToM abilities in adults with ASDs. One example is the Cambridge Mind-reading (CAM) face-voice battery (Golan, Baron-Cohen, & Hill, 2006), which requires participants to recognise complex mental states and emotions from video clips of faces and voice recordings. Findings from this study showed that individuals with AS were poorer at identifying mental states from both faces and voices, compared to age and IQ matched controls. Furthermore, the AS group recognised fewer mental state concepts than control participants.

A further example of a video-based task is the Empathy Accuracy Paradigm (EAP; Roeyers et al., 2001; Ponnet et al., 2004; Ponnet, Buysse, Roeyers & De Clercq, 2008). This test comprises two video-clips of two strangers engaging in a one-to-one conversation. The video-clips vary in structure and the participant is required to infer the thoughts and feelings of the targets. The EAP has proven successful in differentiating individuals with AS from typically developing controls. For instance, while the AS group evidenced comparable performance to controls on the Reading the Mind from the Eyes Test and Strange Stories, findings revealed significant group differences for the second (less structured) video recording. The conversation in the first video is primarily focused on a board game, whilst the second video is more representative of everyday social encounters and involves the targets ‘getting to know each other’. The relative difference between the groups on the two videos suggests that less structured conversations may demand greater communication skills in order to navigate the more unfamiliar and complex social terrain. Consequently, these findings may explain why some individuals with AS are able to pass structured measures of ToM in lab-settings, while demonstrating substantial social-emotional difficulties in their everyday life.

The Movie for the Assessment of Social Cognition (MASC; Dziobek et al., 2006), is another example of a more ecologically valid and complex measure of ToM. The MASC involves watching a film about four individuals interacting in an everyday social context (e.g. conversing during a meal), and empirically examines the participant’s ability to ascribe mental states to the actors featured in the movie. The film is paused at 45 different points, and participants are asked questions relating to the characters thoughts, feelings, and intentions (e.g., “What is Betty thinking?”, “What is Cliff feeling?”, “Why is Michael doing this?”). Studies investigating mind-reading using the MASC have revealed significant deficits in adults with AS. Findings showed

that, compared to neurotypical controls, individuals with AS experienced greater difficulties in inferring the mental states of actors' (Dziobek et al., 2006; Dziobek, Fleck, Rogers, Wolf, & Convit, 2006). Importantly, results from this study showed that the MASC was more accurate in differentiating groups based on ToM abilities, than tests using more traditional formats (e.g., the RMET and Strange Stories tests). In addition, the MASC has also been successful in detecting subtle ToM impairments in other disorders of social cognition, such as borderline personality disorder, schizophrenia, and narcissistic personality disorder (Montag, Dziobek, et al., 2011; Preißler, Dziobek, Ritter, Heekeren, & Roepke, 2010; Ritter, Dziobek, Preißler, Rüter, Vater, Fydrich, et al., 2010).

Although some paradigms offer increased sensitivity to more subtle ToM deficits, lab-based social situations mainly offer a structured environment that potentially conceal much of the mild impairments hindering social interaction in real world settings. For instance, certain studies have allowed participants to complete the EAP in their own time and found that individuals with AS took significantly longer, relative to neurotypical controls (e.g., Ponnet et al., 2004). Nevertheless, real-life social interactions require an individual to infer thoughts and feelings in a rapid and instantaneous manner. Thus, while ToM may largely be intact, delays in interpreting and responding to another person's mental state may lead to undesirable social outcomes, such as inappropriate behavioural responses to emotional states (e.g., changes in facial expressions and helping behaviour; Dziobek et al., 2008). Given that these examinations primarily focus on observed social interaction between two targets, they offer limited insight into the intricate demands of everyday interactions, which necessitate bi-directional communication, 'online' usage of ToM, and the ability to adjust behaviour in response to changing social cues.

Self-report questionnaire measures of empathy have received similar criticisms with respect to ecological validity (Dziobek et al., 2008). It has also been argued that responding accurately to questions about one's empathic abilities requires abstract thinking and self-reflection, and that individuals with ASDs often experience difficulties in these precise areas (Happé, 2003). Conversely, however, some studies suggest that these individuals do possess adequate self-awareness and are able to demonstrate insight into their interpersonal difficulties (e.g., Baron-Cohen et al., 2004; Berthoz & Hill, 2005; Petrides, Hudry, Michalaria, Swami, & Sevdalis, 2011). One explanation for this discrepancy is that most of the studies examining empathy have

focused on ASD groups with spared cognitive abilities, such as AS and HFA. Therefore, it is likely that the intact cognitive abilities of these individuals afford insight into the social and emotional difficulties they encounter (Petrides et al., 2011).

Despite some incongruities, these findings dovetail with the notion that individuals with ASDs have atypical empathic functioning. However, it must be borne in mind that these tests measure the cognitive component of empathy only and therefore, do not provide sufficient insight into the affective aspects of the construct. One task which aims to address such a limitation is the multifaceted empathy test (MET; Dziobek et al., 2008). The MET is a photo-based measure that allows for the simultaneous and independent assessment of cognitive and affective empathy in a more ecologically valid manner than traditional self-report and behavioural measures. This test consists of 23-pairs of photographs depicting individuals in emotionally charged situations (e.g., an elderly man standing alone in a messy kitchen and looking sad). The cognitive component of the MET requires participants to infer the mental states of the pictured individuals by selecting one of four mental state descriptors. Once the participant has given their response, the experimenter provides feedback about the correct answer. Then, to assess affective empathy, participants are required to rate their emotional reaction in response to the pictures presented. Similar to findings from self-report studies (e.g., Baron-Cohen & Wheelwright, 2004; Rogers et al., 2007), the MET suggests that while individuals with AS experience significant impairments in the cognitive aspects of empathy, they do not differ from neurotypical controls in terms of affective empathy.

### *1.5.2 Executive Function*

As discussed earlier in this chapter, executive function is an umbrella term that refers to a set of higher-order cognitive mechanisms facilitating the physical, emotional, and social self-control required to initiate and maintain goal-directed actions (Corbett, Constantine, Hendren, Roche, & Ozonoff, 2009; Lezak, 1995; Pennington & Ozonoff, 1996). Intact executive function allows one to exhibit flexible behaviour, use appropriate problem solving strategies in diverse situations, and to process task-relevant cues in the presence of competing irrelevant information (Miyake & Shah, 1999; Solomon, Ozonoff, Ursu, Ravizza, Cummings, Ly, & Carter, 2009).

Considerable attention has been directed towards understanding the role of executive dysfunction in ASDs (Hill, 2004a,b; Pellicano, 2012). This is primarily due



to the influential theory proposing that core features of the disorder may reflect an underlying deficit in executive function (Ozonoff et al., 1999; Pennington & Ozonoff, 1996). To date, numerous studies have related atypicalities in executive domains to symptoms of rigidity and perseveration (Robinson et al., 2009; Mostert-Kerckhoffs, Staal, Houben, & de Jonge, 2015). In addition to the non-social characteristics of ASDs, difficulties in everyday social interaction have also been attributed to impairments in higher-order cognitive functioning (Yoshida et al., 2010).

Over the past two decades, the executive dysfunction theory of autism has received substantial support from neuropsychological research, with deficits being reported in multiple domains of the construct across all age groups (e.g., Geurts et al., 2009; Hill & Bird, 2006; Hughes & Russell, 1993; Ozonoff, Pennington, & Rogers, 1991; Ozonoff, Cook, Coon, Dawson, Joseph et al., 2004). Nonetheless, it is worth noting that typical performance has also been documented (e.g., Barnard et al., 2008; Goldberg, Mostofsky, Cutting, Mahone, Astor, Denckla et al., 2005; Ozonoff & Jensen, 1999).

This portion of the General Introduction will provide a brief review of all four executive function domains.

#### *1.5.2.1 Planning*

Planning refers to a complex process in which a series of formulated actions must be monitored, assessed, and updated on a continuous basis (Hill, 2004a,b). The Tower of Hanoi (ToH), Tower of London (ToL), and the Stockings of Cambridge (SoC) tasks are all classic measures of planning and problem solving ability. These tasks typically require the participant to plan a sequence of disc moves in order to match a pre-determined goal state. The participant is then required to implement the moves one by one in accordance with three specific rules and in as few moves as possible (e.g., two, three, or four moves, depending on the level of difficulty).

Studies using the Tower tasks have frequently reported ASD-related deficits in planning. Findings have shown that children with ASDs have significantly poorer planning ability when compared to age-matched healthy controls (Lana & Goldberg, 2005; Ozonoff & Jensen, 1999). A similar pattern has also emerged from studies comparing individuals with ASDs to age-matched clinical groups diagnosed with various other neurodevelopmental conditions, such as ADHD, dyslexia, and Tourette's syndrome (Bennetto, Pennington, & Rogers 1996; Geurts et al., 2004; Ozonoff &

Jensen, 1999; Ozonoff & McEvoy, 1994; Ozonoff et al., 1991; Verte, Geurts, Roeyers, Oosterlaan, & Sergeant 2005).

In contrast to the findings outlined above, studies employing computerised versions of the Tower task (e.g., SoC) have reported preserved planning ability for autistic children with normal IQs. For instance, Corbett et al., (2009) and Goldberg et al., (2005) found that planning performance on the SoC did not differ between the HFA, ADHD, and age-matched control groups. Using the same task, Happé and colleagues (Happé, Booth, Charlton, & Hughes, 2006) reported typical performance for a group of children diagnosed with ASDs and also found that older children (aged 11-16) made fewer moves when solving problems, compared to younger children (aged 8-11). This led to the notion that planning difficulties may be related to one's level of general intellectual functioning and developmental maturation, rather than being ASD-specific.

Nevertheless, there have also been reports of impaired planning in ASD groups with IQs in the normal range. For instance, Landa and Goldberg (2005) documented impaired planning on the SoC, with autistic individuals experiencing difficulties across all levels of this measure. Using the same computerised variant of the Tower task, Hughes et al. (1994) also reported similar planning deficits for those with ASDs. This study compared a group of participants with autism to two control groups; the first matched for age and mild learning disability, and the second matched for verbal and nonverbal mental-age. Findings revealed that the autism group demonstrated significantly poorer performance on the SoC task, relative to the control groups. However, unlike Landa and Goldberg (2005), Hughes and colleagues found that ASD-related planning deficits were only evident at the most difficult level of the Tower task (e.g., puzzles requiring four or five moves to reach the end-state, compared to puzzles requiring two or three moves). Thus, rather than having a global deficit, this study indicates that individuals with autism experience difficulties with the more complex and demanding aspects of planning. These findings are of particular importance, as successful navigation of daily life is likely to require highly sophisticated planning abilities. Therefore, any form of deficit in this executive process, whether it be at the simple or more complex level, is likely to have a profoundly negative impact on everyday functioning.

Taken together, results from studies using Tower tasks suggest that ASD-specific difficulties in planning may extend from childhood, through to adolescence,

and into adulthood. However, it is important to note that planning deficits in autism have also been reported in studies using alternative measures. For instance, using the Trail Making test (TMT; Army Individual Test Battery, 1944), Rumsey and Hamburger (1988) reported the presence of planning deficits in a small group of adult males diagnosed with ASDs. The TMT is an extensively used neuropsychological measure which involves connecting a series of encircled letters and numbers in an alternated numeric and alphabetic order (e.g., 1-A-2-B-3-C etc.), as quickly as possible. Findings from this study revealed that the ASD group exhibited greater impairments on the TMT, when compared to a sample of age- and IQ-matched control males. In support of these results, a later study by Hill and Bird (2006) also found that individuals with AS were significantly slower on this task relative to their typically developing counterparts. However, this effect disappeared once psychomotor speed was taken into account, suggesting that group differences on this task reflect difficulties in psychomotor processing, rather than executive dysfunction.

In addition, research by Hughes (1996) has revealed autism-related impairments in the planning of simple motor actions. Participants in this study were required to perform a sequence of hand movements that resulted in either a comfortable or awkward final position. Results showed that in comparison to matched control groups, autistic children were more likely to finish their movement in an awkward position. Consequently, this finding suggests that children with ASDs experience difficulties in their ability to plan ahead, as they were less likely to take the final comfort state into consideration when formulating hand movements.

Conversely, studies using the same task have reported preserved motor planning ability in ASDs. For example, van Swieten colleagues (van Swieten, van Bergen, Williams, Wilson, Plumb, Kent, et al. 2010) found no significant differences in movement between the ASD and typically developing groups, suggesting that children with autism were equally able to take final hand position into consideration. Moreover, Mari and colleagues (Mari, Castiello, Marks, Marraffa, & Prior, 2003) found that performance on a kinematic reach-to-grab task was dependent upon general cognitive functioning, rather than autism per se.

Thus, while there appear to be several reports of autism-related planning impairments, a closer inspection of these studies reveals important discrepancies and highlights the need for further investigation. Findings from the reviewed literature indicate that autism may not be the sole factor underlying deficits in this domain, and

that the presence of learning difficulties may also impede successful planning. In fact, Hill (2004) suggests that although ASDs may play an influential role in planning deficits, autism in conjunction with a learning disability may result in an additive impairment. The same may also be true for co-occurring neuro-developmental and psychiatric conditions, as numerous studies have reported high co-morbidity between autism and other disorders of executive function, such as ADHD, depression, OCD, schizophrenia, and tic disorders (Baron-Cohen et al., 1999; Mayes, Calhoun, Mayes, Molitoris, 2012; Taurines, Schwenck, Westerwald, Sachse, Siniatchkin, & Freitag, 2012). Intuitively, the presence of co-occurring diagnoses should give rise to more pronounced deficits in neuropsychological functioning. At present, however, we know very little about the potential additive effects coexisting conditions and how this may impact planning performance for those with autism. As a result, further research examining autism groups with and without learning difficulties and comorbid disorders is necessary to help advance our understanding of planning ability in ASDs.

Another important issue relates to the measures used to assess the construct of planning. For instance, the TMT and Tower tasks do not necessarily provide a ‘pure’ assessment of planning ability, as they are complex instruments that potentially call upon multiple executive domains. Thus, one must be cautious when interpreting results from such tasks, as poor performance could reflect a more general impairment in cognitive processing, rather than a particular executive deficit (Phillips, Wynn, McPherson, & Gilhooly, 2001; Owen, 1997). Furthermore, research suggests that variations in task administration may influence a participant’s problem-solving strategy and the executive processes used to perform the test (Koppenol-Gonzalez, Bouwmeester, & Boonstra, 2010; Phillips et al., 2001). For instance, instructing participants to reach a solution in the minimum number of moves possible is argued to provide a more accurate measure of planning ability on the ToL. However, when participants are given the opportunity to try different possibilities before completing the problem, ToL performance may reflect other executive processes, such as inhibition and working memory, rather than planning alone (Koppenol-Gonzalez et al., 2010). Future research should therefore address the issue of task administration when assessing planning performance via Tower tasks.

### *1.5.2.2 Cognitive Flexibility*

Impaired cognitive flexibility, or ‘set-shifting’, has frequently been linked to the perseverative and stereotyped behaviours associated with ASDs. One commonly used measure of cognitive flexibility is the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948; Heaton, Chelune, Talley, Kay, & Curtiss, 1993), which generally involves sorting a series of cards based on one of three perceptual dimensions (e.g., colour, number, and shape). This task requires the participant to identify the correct sorting rule through trial and error and accuracy feedback (e.g., ‘correct’ or ‘incorrect’). Once the categorising principle has been discovered and the participant makes ten consecutive correct responses, the sorting rule shifts from one dimension (e.g., shape) to another (e.g., number) without warning. There is no time limit on the WCST and the task finishes once the participant successfully completes all six shifts, or when the maximum number of trials is reached.

Performance is generally assessed in terms of the number of categories completed (e.g., No. of shifts), number of perseverative errors (e.g., repetitive response to changing stimuli), and number of non-perseverative errors (e.g., failure to maintain set following five consecutive correct responses; Barceló & Knight, 2002; Greve et al., 2002). More recently, computerised versions of this test have adopted the shifting efficiency measure proposed by Cianchetti and colleagues (Cianchetti, Corona, Foscoliano, Scalas, & Sannio-Fancello, 2005). According to this scoring method, a participant is awarded 6 points for each shift that is successfully completed and an additional point for each remaining trial, provided that all shifts are made before reaching 120 trials. For instance, a participant who has made all five shifts in 100 trials would receive a shifting efficiency score of  $5*6 + (120-100) = 50$ .

Several studies employing the WCST have reported higher rates of perseverative errors for those with autism. This suggests that individuals with ASDs experience significant difficulties in shifting from one sorting rule to another, despite receiving accuracy feedback. Importantly, these findings have emerged from studies comparing ASD groups to typically developing controls and to clinical controls diagnosed with ADHD and Tourette syndrome, (Ozonoff & Jensen, 1999; Shu, Lung, Tien, & Chen, 2001).

Moreover, studies matching participants based on general cognitive ability have found a similar pattern of results. For example, Rumsey and Hamburger (1988) reported a higher percentage of perseverative errors for autistic adults with IQs in the

normal range, relative to their matched peers. In addition to perseverative responses, later investigations also found autism-related impairments on other aspects of the WCST, when comparing ASD groups to clinical and typically developing controls (Kaland, Smith, & Mortensen, 2008; Guerts et al., 2004; Ozonoff & McEvoy, 1994; Ozonoff et al., 1991; Verte et al., 2005; Verte, Geurts, Roeyers, Oosterlaan, & Sergeant, 2006) as well as dyslexic individuals (Rumsey & Hamburger, 1990).

Nonetheless, it is worth noting that not all individuals with autism exhibit impairments on this measure of cognitive flexibility. For instance, Minsheu, Goldstein, Muenz, and Payton (1992) found no group differences in perseverative errors when administering the WCST to a group of adults and adolescents with autism (FSIQ above 70) and to a control group matched on age, IQ, and gender. Results from Hill and Bird's (2006) study also revealed no statistically significant differences in shifting ability between individuals with AS and typically developing controls on a modified version of the WCST (mWCST; Nelson, 1976). Likewise, numerous other investigations report comparable levels of perseverative errors between ASD groups and matched peers, after controlling for verbal ability (e.g., Liss, Fein, Feinstein, Waterhouse, Allen, Dunn, et al., 2001; Lopez, Lincoln, Ozonoff & Lai, 2005, Rumsey, 1985). These results appear to contradict those reported in studies exerting a stricter control over IQ and suggest that perseverative response styles may be related to verbal ability. Thus, controlling for verbal IQ in future investigations may contribute to a clearer understanding of WCST performance in autism.

While frequently used as an index of cognitive flexibility, it has been argued that the WCST cannot be regarded as a pure measure of this component (Geurts et al., 2009), since successful performance depends on multiple executive processes (e.g., generation of sorting principles, working memory to hold the sorting rule, using feedback to inhibit pre-potent responses, and detecting change and rule-switching). Consequently, this makes it extremely difficult to tease apart the factors contributing to task failure in ASD groups and may provide an explanation for the discrepant findings in the EF literature.

One measure which is thought to provide a clearer assessment of cognitive flexibility is the Intra-dimensional/Extra-dimensional (ID/ED) shift task from the Cambridge Neuropsychological Test Automated Battery (CANTAB). This task is presented in 9 stages and consists of multi-dimensional stimuli (e.g., shapes and lines) that increase in complexity as the test progresses. The first 5 stages determine whether

the participant is able to discriminate and learn from feedback. In stage 6, the ID-shift takes place and the participant is introduced to new shapes and lines, but they are required to continue responding to the shape dimension. At stage 7, ID-reversal, the previously irrelevant shape becomes the response target and in stage 8, the ED-shift, shapes are no longer relevant and the target dimension shifts to lines. At the final stage, ED-reversal, the participant is required to respond to the previously irrelevant line.

The key variables of interest on the ID/ED are the number of errors committed and the number of trials taken to achieve criterion on the last 4 stages. If the participant fails to achieve criterion (six consecutive correct responses) at a given stage, the test is terminated and the maximum number of errors (25) is recorded for all subsequent stages not administered.

Studies using the ID/ED have reported autism-specific deficits in cognitive flexibility. For instance, Hughes, Russell, and Robbins, (1994) found that children and adolescents with ASDs performed more poorly on the final stages of this test than typically developing and mildly learning delayed controls. Similarly, Ozonoff et al., (2004) found that individuals with ASDs were impaired in ED shifting, relative to controls matched on age, gender, and IQ. This particular finding suggests that although the ability to shift within a dimension is intact for those with autism, the ability to shift between stimuli dimensions is significantly impaired.

A later investigation by Yerys and colleagues (Yerys, Wallace, Harrison, Celano, Giedd, & Kenworthy, 2009) also documented autism-related deficits in ID/ED performance. Findings from this study showed that while children with high functioning autism achieved as many ED shifts as typically developing controls, they made significantly more errors than controls on the ED-reversal stage. This result suggests that the HFA group require additional feedback in order to successfully complete the final level. Importantly, by establishing a positive association between ED-reversal difficulties and restricted and repetitive behaviours, this study highlights set-shifting as a potential intermediate phenotype for ASDs. Intermediate phenotypes comprise neuro-cognitive processes which function as a link between the observed behavioural features of clinical disorders and their genetic underpinnings (Gottesman & Gould, 2003). Consequently, using set-shifting as an intermediate phenotype has the potential to inform the development of gene-brain-behaviour models of autism and help advance our understanding of its complex aetiology (Yerys et al., 2009).

Collectively, these reports indicate atypical cognitive flexibility in autism and further highlight the ID/ED test as a promising measure of set-shifting ability. Nevertheless, similar to the WCST, results remain far from consistent because not all studies utilising this measure report impaired performance for those on the autism spectrum. For instance, while Corbett et al. (2009) found ASD-related difficulties on the D-KEFS Category Switching task, findings revealed no deficiencies in relation to ID/ED performance. Likewise, Edgin and Pennington (2005) reported typical set-shifting ability for children diagnosed with ASDs, and others have also found that individuals with HFA do not differ from groups with ADHD or neurotypical controls in this domain of executive functioning (Goldberg et al., 2005; Happé et al., 2006). Importantly, a further report showed that individuals with HFA outperformed age- and IQ-matched controls on certain aspects of the ID/ED task (Landa & Goldberg, 2005).

Taken together, these findings highlight the lack of convergence across studies investigating cognitive flexibility in autism and underscore the need for further research. One factor which may help explain the apparent inconsistency in results is methodological variation (e.g., sample size, age, comparison groups, general cognitive ability, task presentation, and autism subtype). There is considerable heterogeneity within the reviewed literature and this, as a result, limits the extent to which one can draw strong conclusions concerning executive processing in ASDs (Corbett et al., 2009; Geurts et al., 2009).

Future research must also address the problem of ecological validity when investigating flexible cognition in ASDs. Although current neuropsychological measures have proved successful in detecting impairments in set-shifting ability, these are limited in their application to everyday settings and provide no information on how one navigates unforeseen changes in daily life (Han, Kim, & Kim, 2012). Therefore, the use of more naturalistic measures involving socio-emotional parameters (Han, Kim, Jang, Park, Kim, et al, 2009) will help advance our understanding of higher order processing in real-world settings, and provide better insight into how cognitive inflexibility impacts functional outcome in ASDs.

#### *1.5.2.3 Response Inhibition*

The response inhibition domain of executive control allows one to suppress irrelevant or interfering information, emotions, and impulses in order to facilitate goal-



directed behaviour (Dempster, 1992; Hoffman, Schmeichel, & Baddeley, 2012; Miyake et al., 2000; Muraven, Shmueli, & Burkley, 2006, p. 524). Difficulties in inhibiting context-inappropriate behaviours are suggested to underlie the defining features of autism (Kana, Keller, Minshew, & Just, 2007; Volkmar, Lord, Bailey, Schultz, & Klin, 2004). However, to date, neuropsychological research investigating inhibitory control in ASDs has yielded variable results.

The Stroop colour-word task (Stroop, 1935) is a classic measure of response inhibition that involves naming the colour that words are displayed in, while ignoring the word representing colour itself (e.g., “green”/”blue”). Results from many studies indicate that ASD groups demonstrate similar levels of interference on this task, when compared to typically developing controls (Christ et al., 2007; Eskes, Bryson & McCormick, 1990; Goldberg et al., 2005; Hill & Bird, 2006; Ozonoff & Jensen, 1999; Russell, Jarrold, & Hood, 1999; though see Corbett et al., 2009). This is in contrast to other neuro-developmental disorders associated with executive difficulties, such as ADHD, OCD, and Tourette’s (Hartston & Swerdlow, 1999; Ozonoff & Jensen, 1999; Savitz & Jansen, 2003; Sukhodolsky et al., 2011).

The Go/No-Go task has also been used to investigate inhibitory control in ASDs. This measure typically requires one to respond as quickly as possible to frequently occurring ‘Go’ stimuli (e.g., triangles), and to withhold responses to infrequent ‘No-Go’ stimuli (e.g., circles). While some results reveal ASD-related deficits on certain aspects of this task (Christ et al., 2007), others suggest typical performance. For instance, Schmitz et al., (2006) found no significant differences in performance when administering this task to adults with and without ASDs. Similarly, Ozonoff and colleagues (Ozonoff, Strayer, McMahon, & Filloux, 1994) found that autistic children with normal IQs did not differ from typically developing controls in the inhibition of neutral responses. Of note, typical inhibitory processing has also been documented for ASD groups in research using the negative priming and stop-signal paradigms (Brian, Tipper, Weaver, & Bryson, 2003; Ozonoff & Strayer, 1997).

Nevertheless, studies administering the Windows task have reported compromised inhibitory control in children with ASDs (Hughes & Russell, 1993; Russell, Hala, & Hill, 2003; Russell, Mauthner, Sharp, & Tidswell, 1991). This task and its variants involve presenting a child with two boxes: one containing a desired object (e.g., chocolate) and one which is empty. In order to win the desired object, the child must point to the empty box, instead of pointing to the box filled with chocolates.

Results obtained from this task suggest that children with ASDs are impaired in their ability to inhibit pre-potent responding.

The Hayling sentence completion test (HSCT; Burgess & Shallice, 1997) has also been used to assess inhibitory functioning in those with autism. In the first part of this test, participants are required to complete the sentence using the most appropriate word as quickly as possible, whilst in the second part they are required to complete the sentence using a word that is unrelated to the context. Findings from Hill and Bird's (2006) study reported poorer performance on both parts of the HSCT for adults with ASDs, in comparison to their typically developing peers. A later investigation by White et al., (2009) also found autism-related impairments when administering the adapted version of this measure (the Modified Hayling Sentence Completion Test for Children (MHSCT-C; Shallice et al., unpublished) to a group of children with ASD and controls matched on age, IQ, and gender. Results showed that the ASD group responded using more inappropriate words on the "correct" trials and were less likely to form a strategy to help suppress the use of related words on the "wrong" trials. However, rather than being a sign of atypical response inhibition, the authors have proposed that poor task performance may instead reflect a generative deficit (e.g., difficulties in the capacity to spontaneously generate novel ideas and responses; Turner, 1997) or difficulties in following the experimenter's cues. Therefore, it remains unclear whether impairments on this measure are a consequence of inhibitory control or influenced by another factor.

Importantly, there have also been reports suggesting that task complexity impacts performance on measures of response inhibition. For instance, while a number of investigations have found typical performance on simple inhibition paradigms (e.g., Go/No-Go), studies administering more complex tasks tapping both response inhibition and working memory (e.g., antisaccade tasks, NEPSY Knock-Tap task; Korkman et al. 1998) have documented ASD-specific impairments (Joseph et al., 2005; Luna et al., 2007; Minshew et al., 1999). Taken together, these results suggest that deficits in inhibitory processes are not universal among individuals with ASDs and may only emerge in the presence of other influential factors.

As with planning and cognitive flexibility, findings from research investigating response inhibition in ASDs have also been inconsistent. Variation in sample characteristics, task complexity, IQ, and psychiatric co-morbidity may explain the lack of convergence in the abovementioned studies. Consequently, future research needs to

exert stricter control over these variables in order to draw more definitive conclusions regarding inhibitory processes in ASDs. A more ecologically valid paradigm that can mimic the demands of real-world environments is also necessary. Current measures of response inhibition do not provide sufficient insight into the deficits impeding an individual's everyday adaptive functioning. Therefore, the development of such tasks in neuropsychological research are needed to help elucidate the nature and extent of executive difficulties in ASDs.

#### *1.5.2.4 Working Memory*

Working memory is another key component of executive functioning and refers to the process of actively maintaining, monitoring, and manipulating information related to goal-directed actions (Baddeley, 1986; 1999; Miyake & Shah, 1999). While some previous research suggests atypical working memory in ASDs, other research has reported intact performance.

One factor which may help explain the inconsistent results is the aspect of working memory indexed. For instance, numerous studies administering manual and computerised measures of spatial working memory (e.g., tasks which involve remembering and recalling the location in which something is perceived) have found ASD-related impairments (Corbett et al., 2009; Cui, Gao, Chen, Zhou, & Wang, 2010; Goldberg et al., 2005; Happé et al., 2006; Landa & Goldberg, 2005; Luna et al., 2007; Morris et al., 1999; Steele, Minshew, Luna, & Weeny, 2007; Verte et al., 2006; Williams, Goldstein, Carpenter, & Minshew, 2005; Williams, Goldstein, & Minshew, 2006; but see Edgin & Pennington, 2005 and Ozonoff & Strayer, 2001). In contrast, the use of digit, letter, and word span tasks (Joseph et al., 2005; Lopez et al., 2005; Williams et al., 2005; Williams et al., 2006; Williams, Happé, & Jarrold., 2008) has revealed comparable performance for individuals with and without ASDs. However, results from studies administering the N-back, a task which requires the participant to indicate whether the current stimulus matches the one shown n (e.g., 1, 2, or 3) steps ago, have been rather mixed. For example, while some report impairments on this task for children with AS (Cui et al., 2010), others indicate preserved ability (Koshino et al., 2005; Ozonoff & Strayer, 2001; Williams et al., 2005). Findings, from studies examining visual working memory using the self-ordered pointing task have also been mixed. Although children with autism have been reported to display atypical

performance on this task (Verte et al., 2006), an earlier investigation by Geurts et al., (2004) revealed no such deficit.

Several factors may contribute to the discrepancies in working memory literature. First of all, variation in sample characteristics (e.g., age, general language and cognitive ability, autism subtype, comorbid disorders etc.) can significantly influence performance. For instance, a study by Dawson et al., (2002) found that autistic children perform similarly to age-matched controls on a measure of spatial working memory, suggesting that deficits in this executive domain may be less salient in early development. In addition, it has also been suggested that level of general cognitive impairment and symptom severity lead to different profiles of working memory deficits (Schuh & Eigsti, 2012). Finally, another important factor to consider is task complexity. Whilst performance on tasks tapping a single component of the working memory domain (e.g., information maintenance via word span) may be spared in ASDs, more complex measures calling upon multiple components (e.g., maintenance and manipulation) appear to be impaired (Boucher, Mayes, & Bingham, 2012; Just & Carpenter, 1992). Taken together, these studies provide valuable insight into the factors underlying conflicting results within the literature and highlight the importance of investigating ASD-related working memory performance in well-matched and homogenous samples.

A recent study by Schuh and Eigsti (2012) aimed to reconcile the discrepant findings in previous research by examining working memory capacity in a sample of carefully selected children with HFA and typically developing controls. All participants were matched for chronological age, gender, non-verbal IQ, and language ability, and were administered a series of tasks measuring spatial, verbal, and phonological working memory. Group comparisons revealed impaired performance across all three tasks for the HFA group, suggesting broad deficits in working memory functioning. Thus, by reporting poor performance on both simple and complex working memory tasks, these findings support and extend previous research documenting ASD-related deficits in this domain.

Furthermore, the authors also reported a strong association between working memory and social difficulties in HFA. Findings from this study showed that working memory capacity accounted for symptom severity over and above non-verbal IQ. As mentioned previously, successful communication requires one to simultaneously process multiple social cues (e.g., facial expressions, body language, gestures etc.) and

to update and integrate this information as necessary. Consequently, the relationship between working memory and social skills suggests that the verbal and non-verbal components of this domain may play an important role in adaptive social interactions. Nevertheless, future investigations must therefore build upon this finding by employing more naturalistic measures that bridge the gap between laboratory environments and everyday settings. In addition, to further investigate the association between higher-order processing and autism symptomatology, future studies must provide a comprehensive assessment of working memory components in well-matched ASD samples. Such investigations may ultimately provide valuable insight into the cognitive mechanisms contributing to ASD-related deficits in real-world functional outcomes.

### *1.5.3 Association between social cognition and executive control in ASD*

Many studies have documented a meaningful relationship between social cognition and executive control in ASD. For instance, studies have shown that along with atypical facial affect processing and mentalisation, individuals with autism exhibit significant deficits in multiple components of executive control (Christ et al., 2007; Dawson, Meltzoff, Osterling, & Rinaldi, 1998; McEvoy, Rogers, & Pennington, 1993; Pellicano, 2007; Robinson Goddard, Dritschel, Wisley, & Howlin, 2009; for reviews see Hill, 2004 and Russo, Flanagan, Iarocci, Berringer, Zelazo, & Burack, 2007). In addition, results from studies assessing both executive and ToM abilities in ASD have consistently revealed a link between the two constructs, independent of age and intellectual ability (Joseph & Tager-Flusberg, 2004; Ozonoff, Pennington, & Rogers, 1991; Pellicano, 2007).

Given the observed association and the coexistence of executive function and ToM deficits in autism, several studies have sought to establish the interrelationships between these cognitive domains in typical and atypical development. Although some researchers (Perner, 1997; Perner, Lang, & Kloo, 2002) argue that intact ToM fosters executive function, stronger support has emerged for the opposing view (Russell, 1997, 2002), viz., that intact executive functioning is a criterion for successful mentalising in individuals with (Pellicano, 2007; Moses, 2001) and without (Hughes, 1998b; Hughes & Ensor, 2007) ASD. Taken together, these findings highlight the importance of executive abilities in successful mentalization, and suggest that the ToM impairments observed in ASD may be potentially signify deficits in executive control.

Less is known about the association between EF and facial affect processing. While there is some data to suggest a meaningful overlap between measures of emotion recognition and executive control in ASD (Oerlemans, et al., 2013), more comprehensive examinations are needed

#### *1.5.4 Dual Assessment of Social and Executive Processing*

As highlighted above, there appears to be a significant overlap between social and executive processes in typical and atypical populations. However, despite these reports suggesting a meaningful relationship between social and executive domains, most studies have examined these processes separately and provide limited insight into how they might interact. In an attempt to reconcile this issue, a number of recent investigations have developed ecologically valid paradigms providing a joint assessment of social and executive processing (a detailed review is presented in Chapter 4, sections 4.1.2 and 4.1.3.).

In real-world settings, these cognitive mechanisms rarely stand-alone and we frequently deploy executive control when navigating complex aspects of social interactions (Schel & Crone, 2013; Ybarra & Winkielman, 2012). Providing a joint assessment of social and executive processing therefore constitutes an important methodological advancement, and may be particularly valuable in advancing our understanding of how they interact to facilitate optimal social performance.

Studies utilising dual assessment paradigms in typically developing populations so far suggest that emotionally-relevant information can interfere with executive control (Tottenham, Hare, & Casey, 2011), and that performing complex social computations is an effortful process, heavily reliant upon executive resources (Apperly, Riggs, Simpson, Chiavarino, & Samson, 2006; Linn, Keysar, & Epley, 2010; Bull, Phillips & Conway, 2008; Mckinnon & Moscovitch, 2007; Qureshi, Apperly, & Samson, 2010). Indeed, examining social information processing in the context of executive control is particularly relevant when considering interpersonal behaviour in ASD. However, despite yielding findings of great value in typically developing individuals, the use of dual assessments paradigms remain considerably sparse in ASD research, limiting our understanding of the executive function and social cognition link in autistic populations.

## **1.6 Associations between social cognition, executive control, and autism severity**

The main assumption underlying atypical neurocognition in ASD is that impairments within this realm account for the key features defining the condition (Lai et al., 2013). If this is indeed the case, then it is reasonable to expect meaningful associations between autism severity and performance on measures indexing social cognition and executive control.

To examine the link between diagnostic severity and neurocognition, studies have typically utilized the Autism Diagnostic Observation Schedule (Lord, Rutter, DiLavore, & Risi, 1999). The ADOS is a semi-structured, interactive observation schedule designed to evaluate social and communicative functioning among those who may have ASD (Lord, Rutter, DiLavore, & Risi, 1999). The assessment entails a series of standardised activities and ‘presses’ designed to elicit behaviours relevant to a diagnosis of ASD. The ADOS-2 consists of five developmentally sequenced modules, each lasting between 40 to 60 minutes. Only one module is administered, depending on the participant’s chronological age and expressive language level. Each module has its own protocol and consists of a standardised diagnostic algorithm comprising a subset of the social and communicative behaviours rated (Lord, et al., 1999; Lord et al., 2000). Whilst there are several ratings for restricted and repetitive behaviours domain, these are excluded from the diagnostic algorithm as they cannot be reliably observed during a relatively brief assessment. Behavioural ratings (e.g., facial expression directed to the examiner) are based on a hierarchy of mutually exclusive definitions which range from ‘0’ (no abnormality) to 2-3 (clearly abnormal). These items are summed and compared to thresholds, which results in a classification of “autism,” “autism spectrum disorder,” or “non-spectrum.”

The Autism Diagnostic Interview-Revised (ADI-R; Rutter, Le Couteur, & Lord 2003) is another measure used to assess ASD. The ADI-R is a standardised, semi-structured interview conducted with a parent or carer who is familiar with the developmental history and current behaviour of the individual being evaluated. The interview is appropriate for the diagnostic assessment of any individual within the age range extending from early childhood to adult life, provided that they have a non-verbal mental age above 2 years. The ADI-R is composed of 93 items and generates scores on three functional domains: social reciprocity, communication, and repetitive behaviours and interests. In comparison to the ADOS, the ADI-R is believed to provide a more detailed assessment of the repetitive behaviours and interests domain

of ASD. For this reason, and where possible, some researchers opt to use the summary scores from the ADI-R when assessing how symptom severity within this domain relates to other areas of functioning in those with ASD.

Whilst there is some evidence to suggest a meaningful overlap between autism severity and atypicalities in social cognition and executive control (reviewed in detail in Chapter 5 [section 5.1.2]), there are two notable gaps within the existing literature. First of all, studies examining these associations have primarily focused on children, leaving adult populations comparatively under-researched. Second, given that researchers have so far taken a dichotomous approach to the examination of social cognition and executive control, understanding of how performance on combined paradigms relates to symptom severity remains considerably limited, particularly in autistic adults. Consequently, addressing this dearth of research is paramount if we are to further our understanding of how independent and concurrent measures of social and executive function relate to diagnostic severity in adults with ASD.

### **1.7 Subclinical Autism Symptomatology**

Converging evidence suggests that all individuals vary along a dimension of social-cognitive ability, ranging from typical development, through ASD, with classic autism at the extreme end (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001b; Constantino, 2011). In support of this continuum view, it has been proposed that undiagnosed relatives of individuals with ASDs may have a genetic disposition toward the expression of the broader autism phenotype, a set of milder, but qualitatively similar traits relating to social, cognitive, and language difficulties (Bishop, Maybery, Maley, Wong, Hill, & Hallmayer, 2004; Constantino et al., 2006; Piven, Palmer, Landa, Santangelo, Jacobi, & Childress, 1997).

Growing evidence has also indicated that the expression of sub-threshold ASD traits may extend beyond relatives of those diagnosed with an ASD into the general population (Baron-Cohen et al., 2001b; Constantino, 2011; Hoekstra, et al, 2008; Jones, Scullin, & Meissner, 2011). More recent studies have reported greater psychosocial and cognitive difficulties in typically developing adults with higher levels of subclinical autism traits (Christ et al., 2010; Gökçen et al., 2014; Jobe & White, 2007; Petrides et al., 2011; Lockwood, Bird, Bridge, & Viding, 2013), suggesting that these individuals may be more susceptible than the general population to ASD-related



impairments and negative outcomes (e.g., poor social skills, peer rejection, and mental health problems).

In sum, assessing autistic traits among typically developing populations is a promising field of enquiry potentially offering broader insight into the social and non-social features of ASDs. A key advantage of examining typically developing individuals with autism symptomatology is that they are more likely to be tolerant of structured testing environments than diagnosed individuals. Thus, we may be able to gain unique insights into the spectrum by employing a wider range of tasks and methodologies when studying this broader population. As a result, the emerging evidence documenting a qualitatively similar (though less severe) pattern of impairments in those with higher-than-typical autism traits, identifies a valuable new avenue of research that has the potential to significantly enhance our understanding of ASD at the clinical and subclinical level.

### **1.8 Comorbid Alexithymia in ASD**

An important consideration when examining social cognition in ASD is its high comorbidity with alexithymia, a sub-clinical personality construct characterized by difficulties in the ability to recognize, express, and distinguish emotional states from bodily sensations (Nemiah, Freyberger, & Sifneos, 1976; Taylor, Bagby, & Parker, 1997).

Studies to date have reported a strong association between alexithymia and the autism spectrum. For instance, while the prevalence of alexithymia is thought to be around 10% in the general population (Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen 1999), alexithymic traits are believed to affect at least 50% of individuals diagnosed with ASDs (Berthoz & Hill, 2005; Hill, Berthoz, & Frith, 2004).

Existing research indicates an association between the degree of alexithymia and deficits in the processing of facial expressions (Jessimer & Markham, 1997; Lane et al., 1996; Swart, Kortekaas, & Aleman, 2009). More recent studies investigating emotion processing in ASDs suggest that co-occurring alexithymia may be responsible for the impairments in empathic functioning (Bird, Silani, Brindley, White, Frith, & Singer, 2010), emotion recognition (Cook, Brewer, Shah, & Bird, 2013), and attention to facial stimuli (Bird, Press, & Richardson, 2011), rather than autism per se.

Based on these findings, future studies aiming to understand the nature of emotion processing difficulties in ASDs should examine the contributing role of

alexithymic traits. Indeed, such research may not only serve to improve our understanding of socio-emotional dysfunction in autism, but also help clarify the inconsistencies and contradictions observed in the literature.

## 1.9 Summary and current thesis

In summary, a large corpus of research suggests that the prefrontal cortex and its related functions, such as social cognition and executive control, follow a prolonged developmental trajectory that extends into the third decade of life. However, despite increasing research on the development of higher-order cognition, little attention has been given to the age-related changes in these processes between middle adolescence and young adulthood. In addition, numerous studies indicate a meaningful overlap between social cognition and executive control, and highlight autism-related deficits in these processes. Nonetheless, given that these studies have primarily focused on assessing social and non-social domains separately, the potential interaction between social and executive functioning remains relatively underexplored. Likewise, despite recent theory and research suggesting a link between autism symptomatology and ASD-related deficits in social and executive function, research profiling these higher-order abilities at the subclinical level remains considerably limited, very little is known about whether autism traits are associated with variability in processing socio-affective information in the context of executive control

This thesis aims to address several important outstanding research questions by providing a comprehensive examination of social and executive processing in typical and atypical populations. **Chapter 2** presents a two-part study where we compare the social and executive function profiles of typically developing mid-adolescents (16-17 years) and young adults (19-22 years) using an extensive battery of tasks. The first part of this study examined multiple aspects of social cognition by utilising a wide-range ecologically valid measures assessing cognitive (MASC; Dziobek et al., 2006) and affective (SAM; Seara-Cardoso et al., 2012) empathy, as well as facial affect processing (Rapid Emotion Recognition Test, RERT; Lockwood & Gökçen, *in progress*). Additionally, the Reading the Mind from the Eyes Test (EYES; Baron-Cohen et al., 2001) was administered as a static measure of ToM to compare its sensitivity to age-related differences against a more naturalistic, video-based, tool (i.e., MASC). The second part of this study examined the executive domains of response inhibition, planning, cognitive flexibility, and working memory, and sought to

determine the interrelationships between measures assessing social and executive processing.

**Chapter 3**, provides a comprehensive investigation of the facial affect processing, empathy, executive function, and ASD trait link in a large sample of typically developing adults and adolescents. The same battery of tasks from Chapter 2 were used to examine whether individuals with elevated levels of autism traits display a similar profile of social and executive function deficits to those observed in ASDs. A further aim was to determine the potential contribution of alexithymia to performance on measures of social cognition, as well as to probe its association with multiple domains of executive control. A final goal was to replicate the interrelationships between social and executive functioning reported in Chapter 2 in a larger sample of participants.

**Chapter 4** examined whether typically developing adults with elevated levels of ASD traits would demonstrate poorer performance on tasks assessing of social and executive processing simultaneously. This question was addressed via a dual-task paradigm examining the interaction between ToM use and executive functioning under varying levels of cognitive load. A test of rapid emotion discrimination in the context of a standard go/no-go task was also administered in order to assess the impact of affective information on executive control.

The final empirical study is reported in **Chapter 5**, which extends the combined paradigms from Chapter 4 to a sample of adults with and without high-functioning ASD. This study investigated potential group differences on concurrent measures of social and executive processing, and examined whether performance deficits on combined paradigms were more pronounced relative to tasks assessing executive control in the absence of socio-affective information. In addition, this study also examined whether performance on combined and neutral measures were related to diagnostic severity in our ASD group. Finally, in **Chapter 6**, the findings from these four empirical studies are summarised and their potential implications are discussed, as well as possible avenues for future investigations.

### *1.9.1 Research Questions*

This thesis aimed to address five outstanding research questions:

1. Are there age-related improvements in higher-order cognition between middle adolescence and young adulthood? (**Chapter 2**).
2. Do typically developing individuals with elevated levels of autism traits display a similar pattern of difficulties in social cognition and executive control to those with a clinical diagnosis of ASD, and could these difficulties be attributed to trait alexithymia? (**Chapter 3**).
3. Are elevated levels of autism symptomatology associated with poorer performance on concurrent measures of social and executive processing? (**Chapter 4**).
4. Do adults with high-functioning ASD experience difficulties in processing socially-relevant cues in the context of executive control, and are these deficits more pronounced relative to neutral measures of executive function? (**Chapter 5**).
5. Does task performance on combined paradigms relate to diagnostic severity of ASD, and are these associations stronger when compared to neutral measures of executive control? (**Chapter 5**).

**2 Higher-order processing during mid-to-late adolescence  
and young adulthood: A comprehensive examination of  
social cognition and executive control**

## 2.1 Chapter Introduction

As outlined in the General Introduction, the frontal networks thought to subserve social cognition and executive function undergo a protracted course of maturation between preadolescence and adulthood. Whilst these higher-order processes have been extensively studied in child, early teen, and adult populations, there is a dearth of research charting the typical development of social cognition and executive control during the mid to later years of adolescence. Furthermore, a growing body of research has highlighted this period as a time of increased vulnerability to mental health problems (see Paus, Keshavan, & Geidd, 2008 for a review). In particular, the emergence of certain psychiatric conditions during adolescence is thought to reflect anomalies in the maturational changes shaping frontal networks (Paus et al., 2008). Consequently, examining normative data is paramount to advancing our understanding of social and executive function development during the later stages of adolescence and early adulthood, and also provides a baseline for studying these processes in atypically developing populations.

### 2.1.1 *Adolescence and higher-order cognition*

Adolescence is characterised by substantial changes in physical, social, and cognitive development (Crone & Dhal, 2012; Patton & Viner, 2007). Those who complete this developmental phase successfully display autonomous behaviour, adaptive decision-making skills, and the ability to effectively navigate complex social environments (Blakemore & Mills, 2014). To date, studies have shown that the neural mechanisms underlying these key skills are subject to profound maturation during adolescence (Steinberg, 2005). In particular, the prefrontal networks supporting higher-order cognitive processing follow a gradual and protracted course of maturation, spanning preadolescence and early adulthood (Casey, Getz, & Galvan, 2008; Giedd, 2008; Giedd et al., 1999; Gogtay, Giedd, Lusk, Hayashi, Greenstein, Valtuzis, et al., 2004; Johnson, Blum, & Giedd, 2009). Neural rewiring during the mid-to late adolescence period involves age-dependent changes in white matter volume and synaptic refinement (Blakemore & Choudhury, 2006; Geidd et al., 1999; Gogtay et al., 2004; Paus, 2005; Sowell, et al., 2003). Therefore, maturation of the frontal regions may serve to enhance the neural circuits relevant for higher-level cognitive skills, such as executive function and social cognition (Blakemore & Choudhury, 2006).

Indeed, numerous studies examining executive processing have indicated age-related linear improvements in multiple domains: response inhibition (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Tamm, Menon, & Reiss, 2002), cognitive flexibility (Huizinga, Dolan, & Van der Molen, 2006), working memory (Anderson, Anderson, et al., 2001), and planning performance (De Luca et al., 2003; Huizinga, et al., 2006; Luciana, Collins, Olson, & Schissel, 2009; Guevera, Martinez, Aguirre, & Gonzalez, 2012; but see Anderson et al., 2001).

Similarly, whilst it was thought that social cognitive abilities were largely established by the age of six or seven (Mills et al., 2014; Wimmer and Perner, 1983), more recent investigations demonstrate advancements beyond childhood and adolescence (Dumontheil, Apperly, & Blakemore, 2010; Thomas et al., 2007). With respect to the developmental progression of affective empathy, the ability to resonate with others' emotional experiences is thought to emerge much earlier than ToM. For instance, studies have found that newborns (Dondi et al., 1999; Martin & Clark, 1987) and older infants (Geangu et al., 2010) display increased signs of distress when presented with the sound of another infant crying. This in contrast to more PFC-dependent functions, such as ToM, which follow an extremely protracted course of development (e.g., Dumontheil et al., 2010).

### *2.1.2 The current study*

Taken together, these findings appear to corroborate the suggestion that age-related advancements in these social and executive function reflect a fine-tuning of the frontal networks supporting higher-level cognition (Blakemore & Choudhury, 2006; Choudhury, et al., 2006; Gaillard et al., 2000; Tamm et al., 2002). However, despite numerous studies yielding support for a prolonged course of development, research to date has primarily focused on child, early teen, and adult populations. As such, there is a considerable lack of research charting the typical development of social cognition and executive control during the mid-to-later years of adolescence. To address this gap in the literature, the present two-part study used a comprehensive battery of tasks to assess the development of higher-order cognitive processing in mid-adolescence (16-17 years) and young adulthood (19-22 years). The first part of this study examined multiple aspects of social cognition by utilising a wide-range of ecologically valid measures assessing cognitive (Movie for the Assessment of Social Cognition, MASC; Dziobek et al., 2006) and affective (Self-Assessment Manikin, SAM; Seara-Cardoso et

al., 2012) empathy, as well as facial affect processing (Rapid Emotion Recognition Test, RERT; Lockwood & Gökçen, in progress). The Reading the Mind from the Eyes Test (EYES; Baron-Cohen et al., 2001) was administered as a static measure of ToM in order to compare its sensitivity to age-related differences against a more naturalistic, video-based, tool (i.e., MASC). The second part of the study assessed the executive domains of response inhibition, planning, cognitive flexibility, and working memory. A final aim was to examine the interrelationships between measures assessing social cognition and executive control.

Based on the findings that the neural circuitry supporting higher-order cognition continues to develop during adolescence, age-related improvements were predicted on tasks assessing social and executive function. Specifically, adults were predicted to demonstrate superior levels of facial affect recognition in comparison to adolescents (H1). Whilst, age-associated improvements were predicted across both measures of ToM (H2), performance differences between adults and adolescents were expected to be greater on the MASC task, relative to the EYES (H3). However, no group differences were expected between adults and adolescents on a measure indexing the affective domain of empathy (H4).

With respect to the second study, adults were hypothesised to display superior performance across all domains of executive processing in comparison to adolescents (H5). In addition, significant associations between measures of social cognition and executive control were predicted (H6). Finally, given the association between higher-order processing and general cognitive ability (Pellicano et al., 2007), an additional aim was to examine the potential effects of IQ on task performance. Therefore, general cognitive ability was incorporated into the study design as a control variable.



## 2.2 Material and Methods: Study 1

### 2.2.1 Participants

Seventy-four healthy participants, 36 young adults and 37 adolescents, were recruited for this study. One participant (adolescent group) was excluded due to missing data on one of the experimental tasks. This left a final sample of 36 young adults (31% male) and 36 adolescents (8% male), aged between 16 and 22 years (adults:  $M = 19.36$  years,  $SD = .80$ ; adolescents:  $M = 16.67$  years,  $SD = .48$ ). As regards to IQ, participants scores on the Wechsler Abbreviated Scales of Intelligence (WASI; Wechsler, 1999) ranged from 72 to 129 ( $M = 99.89$ ,  $SD = 12.77$ ). There was a statistically significant difference in WASI scores ( $t(70) = 7.21$ ,  $p < .001$ ) between the two groups, with adult participants ( $M = 108.17$ ,  $SD = 10.54$ ) scoring higher than adolescents ( $M = 91.61$ ,  $SD = 8.86$ ). Written informed consent was obtained from all participants and parents of adolescents. The study protocol was granted ethical approval from the UCL Research Ethics Committee. Participants were recruited via a university subject pool and a London-based sixth-form college.

### 2.2.2 Measures

#### 2.2.2.1 Facial Affect Processing

The Rapid Emotion Recognition Test (Lockwood and Gökçen, in progress) is a computerised assessment of emotion identification. Grey-scale facial stimuli were derived from the Karolinska Directed Emotional Faces database (Lundqvist, Flykt, & Öhman, 1998), and the task was programmed using JavaScript and presented in Google Chrome. The RERT requires participants to focus on a centrally located fixation cross for 500ms. Subsequently, a male or female face depicting one of five basic emotions (fear, anger, disgust, happy, or sad), or a neutral expression appears on the screen for 100ms. The image is then backward masked for 50ms. At the end of this sequence, the participant is required to identify which emotion the face displayed by selecting one of six options. The next trial begins immediately after the participant's response or after 4000ms if no response is made. The RERT consists of 144 trials (24 per emotion), divided into three blocks of 48 trials. A percentage of error rate is calculated for each emotion, with higher rates indicating greater difficulties in emotion recognition (see Appendix 1 for further details).

### 2.2.2.2 Assessment of Empathic Processing

#### *Static ToM*

The Reading the Mind from the Eyes Test (EYES) is a visual-static measure of theory of mind. This task requires participants to view pictures of eye gazes and judge which of four adjectives best describes the mental state depicted in the images. Adult participants completed the revised 36-item adult version of the test (Baron-Cohen, Wheelwright, Hill, et al., 2001), whilst the adolescents completed the 28-item child version. One point was assigned for all correct answers and a percentage of accuracy score was calculated for each participant.

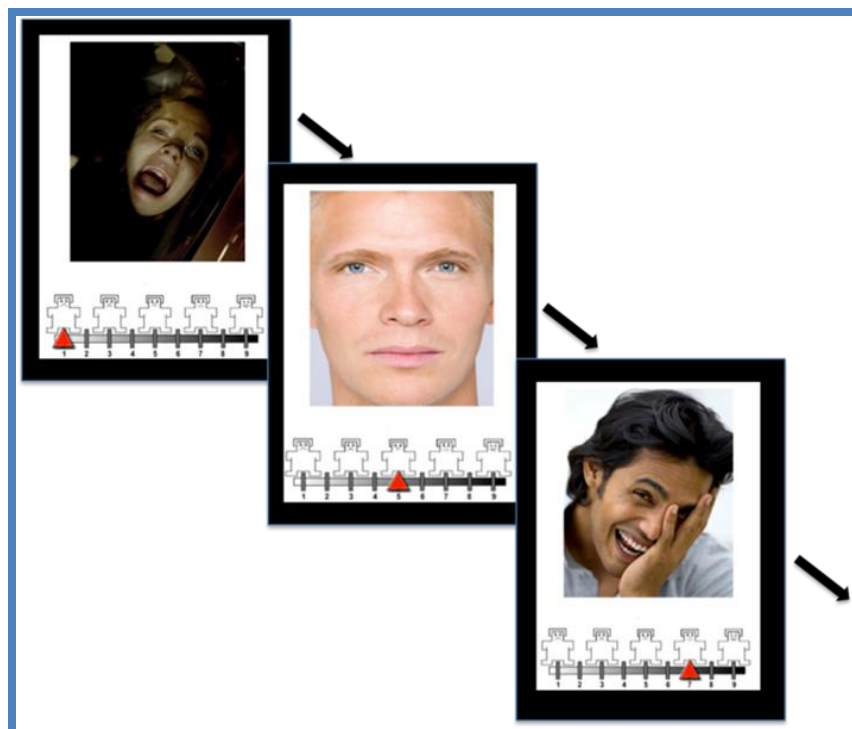
#### *Naturalistic Theory of Mind*

The Movie for the assessment of Social Cognition (MASC; Dziobek et al., 2006) is an ecologically valid mentalising task that approximates the demands of real-life social interactions. The MASC involves watching a 15 minute movie about four characters spending an evening together having dinner. The film covers topics on dating and peer relationships, and requires the participants to process information from multiple channels of communication (e.g., visual, auditory, & verbal). The film is paused at 45 points, and questions concerning the characters' thoughts, feelings, and intentions are asked (e.g., "What is Sandra feeling?", "What is Betty thinking?," "Why is Michael doing this?"). Answer options are presented in a multi-choice format consisting of four response options: (1) hypermentalizing, (2) under/reduced mentalizing, (3) no mentalizing, and (4) accurate mentalizing. A total score, varying from 0 to 45, was calculated by summing up all correct responses.

#### *Affective Empathy*

The Self-Assessment Manikin Faces Task (SAM-Faces; Affective Empathy Task) provides an ecologically valid assessment of affective empathy (Seara-Cardoso et al., 2012; Lockwood et al., 2013). It requires participants to rate their own affective response to images depicting sad, fearful, angry, happy, or neutral facial expressions. Participants respond to each image using a 9-point valence scale, ranging from a low-spirited manikin ('1') to a cheerful one ('9'), going through a neutral manikin in the

middle ('5'). Images were presented in a randomized for each participant and the ratings for sad, fear, and anger were reverse scored so that higher scores reflected greater distress when viewing others' negative emotions. These variables were subsequently transformed into z-scores, and summed along with ratings for happy faces to form a composite score.



**Figure 2.1** Examples of three different trials of the SAM-Faces task

## 2.3 Results and Discussion

### 2.3.1 Preliminary Analysis

All study variables were visually inspected for normal distribution via Quantile-Quantile (QQ) plots. Minor to moderate deviations from normality were detected for the following variables: EYES (Adult group), RERT Fear (Adult group), RERT Sad (Adult and Adolescent groups), and RERT Happy, (Adult and Adolescent groups). All remaining variables demonstrated approximate normality.

As stated by the central limit theorem (Field, 2002), provided that the sample size is sufficiently large ( $> 30$  or  $40$ ), the distribution of sample means will be approximately normal regardless of the shape of the data. Given that the Adult and Adolescent groups in the current study contain over 30 participants, minor departures from normality are unlikely to cause a major problem.

### 2.3.2 Facial Affect Recognition

Group differences in emotion recognition were examined using multivariate analysis of covariance (MANCOVA). Error rates for each emotion (fear, anger, disgust, sad, and happy) were entered as dependent variables, participant group (young adults vs. adolescents) was entered as the independent variable, and IQ was entered as the covariate. The effect of group was significant, ( $F(5, 65) = 4.68, p = .001, \eta^2 = 0.27$ ; see Figure 2.2.), with adolescents demonstrating higher error rates relative to adult participants.

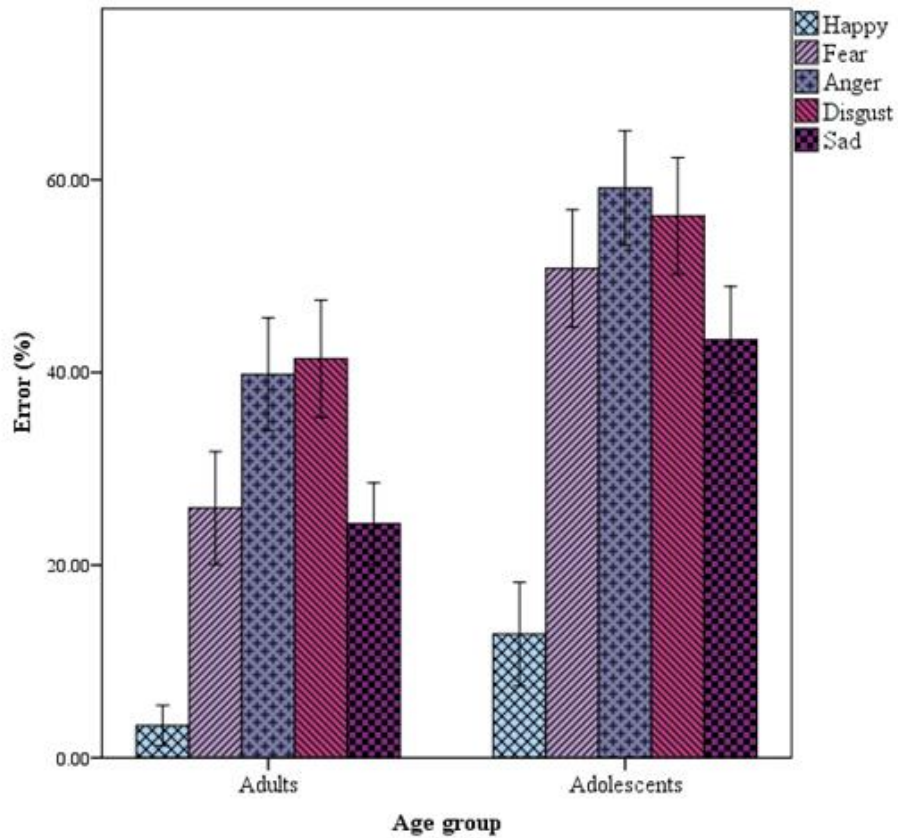
Follow up ANOVAs revealed a significant effect of group on all emotions (see Table 2.1. for descriptive statistics). In comparison to young adults, adolescents were less accurate in recognising emotional expressions of fear ( $F(1, 69) = 13.95, p < .001, \eta^2 = 0.17$ ), anger ( $F(1, 69) = 9.87, p = .002, \eta^2 = 0.13$ ), disgust ( $F(1, 69) = 6.58, p = .013, \eta^2 = 0.09$ ), and sadness ( $F(1, 69) = 8.41, p = .005, \eta^2 = 0.11$ ). Happiness ( $F(1, 69) = 3.68, p = .059, \eta^2 = 0.05$ ) indicated a trend towards significance. Finally, the covariate, IQ, was significantly related only to the recognition of sad facial expressions ( $F(1, 69) = 4.80, p = .032, \eta^2 = 0.07$ ). IQ revealed no other significant effect in the model (Fear:  $F(1, 69) = 1.49, p = .266$ ; Anger:  $F(1, 69) = .402, p = .528$ ; Disgust:  $F(1, 69) = .012, p = .913$ ; Happiness:  $F(1, 69) = .866, p = .355$ ). These findings yield strong

support for the hypothesis that adolescents would demonstrate poorer facial affect recognition, than young adults (H1).

**Table 2-1 Descriptive statistics for accuracy scores across all emotions for adults and adolescents**

<b>RERT Emotion</b>	<b>Participant Group</b>	
	<b>Adult (N= 36)</b>	<b>Adolescent (N = 36)</b>
	<b>Mean (SD)</b>	<b>Mean (SD)</b>
Fear	25.93 (17.34)	50.81 (18.06)
Anger	39.81 (17.29)	59.14 (17.50)
Disgust	41.44 (17.98)	56.25 (17.89)
Sadness	24.31 (12.50)	43.40 (16.35)
Happiness	3.36 (6.21)	12.85 (15.89)

*Note.* RERT, Rapid Emotion Recognition Test.

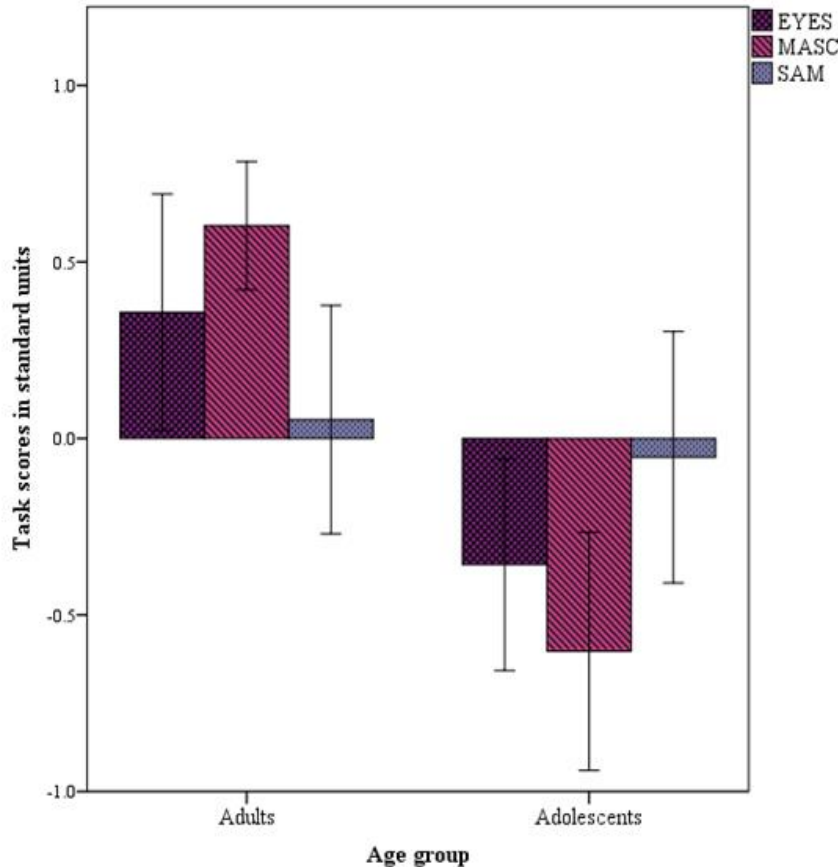


**Figure 2.2 Mean percentage of RERT errors for adults and adolescents as a function of emotion**

*Error bars represent standard errors.*

### 2.3.3 Empathic processing

Multivariate analyses were used to examine group differences in empathic processing. Scores on the EYES, MASC, and SAM tasks were entered as dependent variables, participant group (young adults vs. adolescents) was entered as the independent variable, and IQ was entered as the covariate. The effect of group was significant, ( $F(3, 67) = 7.04, p < .001, \eta^2 = 0.24$ ; see Figure 2.3.), with adolescents demonstrating poorer empathic processing abilities in comparison to adults.



**Figure 2.3 Mean scores on measures of cognitive and affective empathy for adults and adolescents.**

*Error bars represent standard errors. Graph is based on standardized dependent variables.*

Inspection of follow up ANOVAs revealed a significant effect of group on the EYES test ( $F(1, 69) = 4.83, p = .031, \eta^2 = 0.07$ ), with young adults ( $M = 82.50\%, SD = 10.89$ ) performing better than adolescents ( $M = 74.64\%, SD = 9.75$ ). Furthermore, there was a significant main effect of group on MASC performance, ( $F(1, 69) = 17.98, p < .001, \eta^2 = 0.21$ ), with adults ( $M = 37.11, SD = 2.74$ ) demonstrating superior mentalizing ability in comparison to adolescents ( $M = 30.94, SD = 5.10$ ). However, with respect to SAM performance, analysis returned a non-significant effect of group, ( $F(1, 69) = .443, p = .508$ ) with adults ( $M = -.05, SD = 1.67$ ) and adolescents ( $M = -.23, SD = 1.83$ ) evidencing similar levels of affective empathy. Finally, the covariate, IQ, revealed no significant effect in the model (EYES:  $F(1, 69) = .124, p = .725$ ; MASC:  $F(1, 69) = .826, p = .367$ ;



SAM:  $F(1, 69) = 2.39, p = .127$ ). Overall, these findings provide strong support for the hypothesis that adolescents would exhibit poorer performance on tasks measuring cognitive empathy (H2), and that this effect would be statistically stronger on the naturalistic MASC task, relative to the EYES. Last, our findings also yield support for comparable levels of affective empathy between adolescents and young adults (H4).

## **2.4 Study 2: Method and Results**

### *2.4.1 Participants*

Sixty-nine participants, 36 adults and 32 adolescents, from the original sample returned to complete the second part of the study. Participants were aged 16-22 (adults:  $M = 19.36$  years,  $SD = .80$ ; adolescents:  $M = 16.66$  years,  $SD = .48$ ), with estimated IQs between 72 and 129 ( $M = 101.72, SD = 11.51$ ). Once again, analysis revealed a statistically significant difference in IQ scores between the two groups ( $t(66) = 7.01, p < .001$ ), with adults ( $M = 108.17, SD = 10.54$ ) demonstrating higher scores in comparison to adolescents ( $M = 91.38, SD = 9.04$ ).

### *2.4.2 Assessment of Executive Functioning*

#### *2.4.2.1 Cognitive Flexibility*

A computerised set-shifting task (Smillie, Cooper, Tharp, & Pelling, 2009) based on the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), programmed in Matlab using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997), was employed to assess cognitive flexibility. Each trial consisted of the presentation of a single card, which varied in three different ways: (1) was blue or yellow in colour, (2) displayed either a '0' or an 'X' on the front, and (3) appeared on the left or right side of the screen. Participants were instructed to sort the cards into two piles by pressing either the '\`' or '/' key (which were marked as 'A' and 'B'). After each trial, participants were provided with feedback on the accuracy of their response.

Participants were told that to learn how to sort the cards accurately, they would need to use the feedback and learn by trial-and-error. An unannounced shift in the sorting

rule occurred after the participant had made 10 consecutive correct responses. In total, five shifts took place during the experiment with each of the rules repeating twice. The task duration was approximately 10 minutes and finished once the participant had successfully achieved all five shifts or once they had completed the maximum number of trials (120), whichever was earlier. Performance was assessed in terms of the total number of shifts made and the shifting efficiency measure proposed by Cianchetti, Corona, Foscoliano, Scalas, and Sannio-Fancello (2005). According to this scoring method, a participant is awarded six points for each shift that is successfully completed and an additional point for each remaining trial, provided all five shifts are made before reaching 120 trials. For instance, a participant who has made all five shifts in 90 trials would receive a shifting efficiency score of  $5*6 + (120-90) = 60$ .

#### *2.4.2.2 Odd-Man-Out*

The odd-man-out (OMO) is similar to the ID/ED measure of set-shifting ability outlined in the previous chapter, and consists of two experimental conditions: perceptual-switching and rule-switching (Ravizza & Carter, 2008). The perceptual-switching condition is made up of four letters (b, i, n, v) and four shapes (cross, hexagon, parallelogram, triangle). A different array of letters (o, s, t, x) and shapes were used in the contextual switching task (circle, diamond, pentagon, square). Participants were required to identify whether the target was a letter or a shape (see Figure 2. 4). A switch occurred when the OMO changed from a letter to a shape or vice versa.

Three of the four stimuli were identical in both conditions and the participant was required to select the letter or shape that did not match. Task presentation was self-paced and the stimuli were presented until the participant made a response. Responses were followed by a 500 ms interval before moving onto the next trial. In all conditions, a row of keys on the computer keyboard was used to record responses. The probability of a switch in target feature was 0.5.

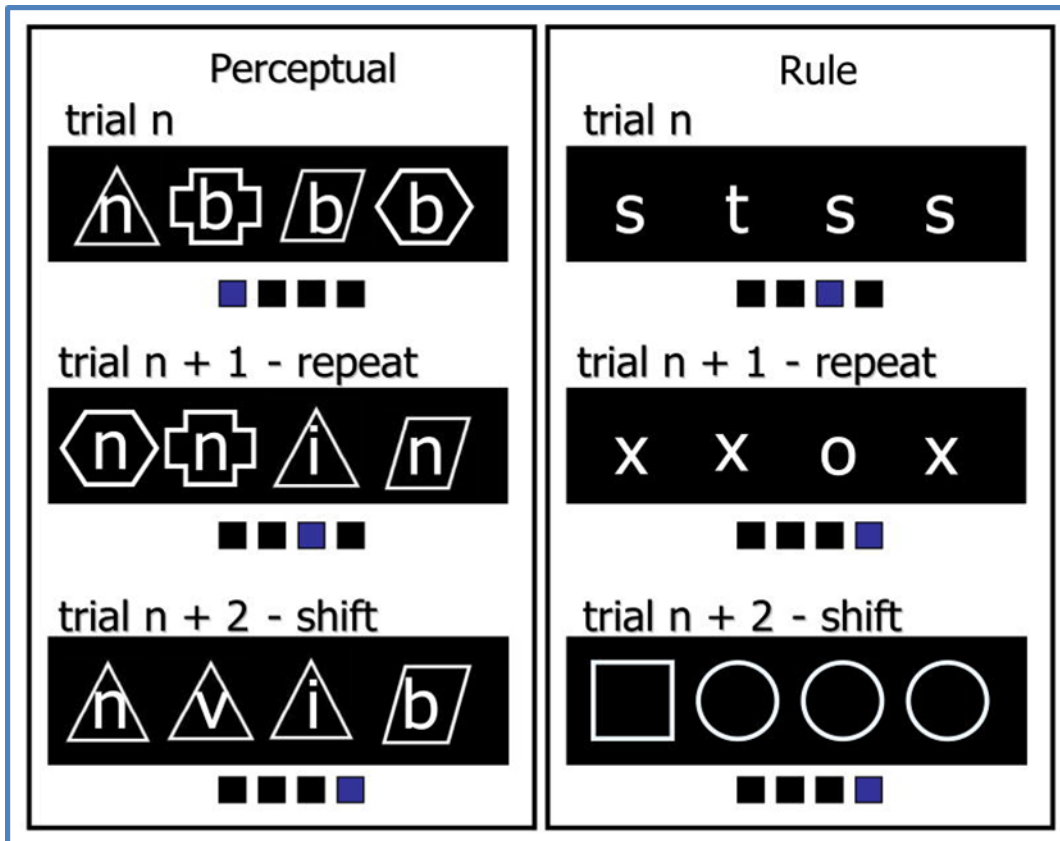
In the rule-switching condition, a change in the target feature signified a shift in the relevant set of stimulus-response mappings. There was one set of response rules for shapes and another for letters. When a switch occurred, participants had to retrieve and implement the appropriate response rule associated with the stimulus. There were few

demands on perceptual switching in this condition. The alternate feature set was not present and so participants did not have to move attention between one type of feature and/or location to another. Once participants identified the stimulus that did not match the others, they pressed a button on the computer keyboard that had been previously memorized for that particular OMO. For example, if the stimuli were “s”, “s”, “o”, and “s”, participants would have to recall the response rule that was associated with an “s” rather than pressing the location of the target. The second through fifth fingers of the right hand were mapped to the letters “s”, “x”, “t”, “o” and circle, diamond, pentagon, and square, respectively.

Both letters and shapes were presented in the perceptual-switching condition. This required participants to shift attention from the previously relevant feature and reorient their attention to the alternate set of features. Contextual information, the stimulus-response rules, remained static in this condition; participants responded in the same way irrespective of whether the OMO target was a letter or a shape and the goal was always the same (i.e., find the OMO). If the OMO was a letter, then all the shapes were different and vice versa when the OMO was a shape. A shift occurred when the OMO switched from one feature set (e.g., shapes) to another (e.g., letters) in successive trials. When the odd letter or shape was identified, participants responded by pressing the button that corresponded to the spatial location of the odd stimulus.

Participants completed one block of trials in each condition and the block sequence was administered in random order. Task instructions were presented at the beginning of each block. The rule- and perceptual-switching conditions contained a total of 256 trials; this ensured that each combination of target dimension (2), target stimulus (4), target location (4), and distractor stimulus (4) was presented at least once.

Prior to the rule-switching condition, participants completed a series of 80 practice trials in which they memorised the stimulus-response mappings. In these practice trials, one stimulus, either a letter or a shape, was presented and participants had to produce the correct response mapping for that stimulus. All participants achieved over 75% correct responses before they received trials in the contextual-switching condition. The primary outcome for this measure was percentage of accuracy and RTs for repeat and shift trials for each block.



**Figure 2.4** Examples of the perceptual and rule shift tasks on the OMO task

### 2.4.2.3 Response Inhibition

The Go/No-Go (Form S3; Vienna Test Systems, 2012) was used to measure response inhibition. This task required participants to respond as quickly and accurately as possible to all individually presented triangles (“go” trials), but avoid responding to the circles (“no-go” trials). The stimuli were presented for 200 ms and the interstimulus intervals were 1000 ms. The Go/No-Go was divided into two blocks of 125 trials, with 19% of the trials being “no-go” and the remaining 81% being “go” trials. Task duration was approximately eight minutes, and the total number of commission errors was used as an index of response inhibition.

#### *2.4.2.4 Planning Ability*

The Tower of London- Freiburg Version (ToL-F; Vienna Test Systems, 2012) was used to assess planning ability. In the computerised version of this task, a wooden frame/object with three vertical rods of different heights is shown on the screen. Participants are presented with a start state and instructed to re-configure the balls to match a desired end state, while following three important rules: 1) Only one ball can be moved at a time, 2) balls cannot be placed outside the rods, and 3) if more than one ball is stacked on a rod, only the top ball can be moved. In addition, participants are instructed to solve each problem in the minimum number of moves stated and to prepare a solution before implementing the moves.

Twenty-eight experimental trials were presented in order of ascending difficulty (four three-move problems, eight four-move problems, eight five-move problems, and eight six-move problems). The main target variable recorded for this task was the number of items correctly solved within a time limit of one minute each. The variable was labelled “Planning ability”.

#### *2.4.2.5 Working Memory*

Working memory was indexed via the N-Back task. There were three levels of difficulty (randomly presented) consisting of 90 trials during which a single letter (A–Z) appeared on the screen individually for 500 ms with an inter-trial interval of 1500 ms. Participants were required to indicate whether the letter presented was a ‘target’ or ‘non-target’ by pressing the ‘1’ or ‘2’ key on a standard keyboard within the 2000 ms trial length. In the first block, the target was a letter that matched the letter presented on the previous trial (1-Back). In the second block, the target was a letter that matched the letter presented two trials earlier (2-Back). In the third and final block, the target was a letter that matched the letter presented three trials earlier (3-Back). Each block consisted of 30 target and 60 non-target trials. Before beginning each block, participants were shown a frame-by-frame example of what constituted a target in that block, and were required to complete a set of 20 practice trials. The N-Back was programmed in E-prime™ and is comparable to version used by Wacker, Chavanon, and Stemmler, (2006). The primary outcome for this measure was WM accuracy (percent correct) for each block.

## 2.5 Results and Discussion

### 2.5.1 Preliminary Analysis

All study variables were graphically assessed for normal distribution via QQ plots. Minor to moderate deviations from normality were detected for the following executive function variables: WCST (Adolescent group), 1-Back (Adolescent group), 2-Back (Adult and Adolescent groups), and 3-Back, (Adult and Adolescent groups). All remaining variables demonstrated approximate normality. Once again, as the Adult and Adolescent groups in the current study contain over 30 participants, slight deviations from normality are unlikely to cause a major problem (central limit theorem; Field, 2002).

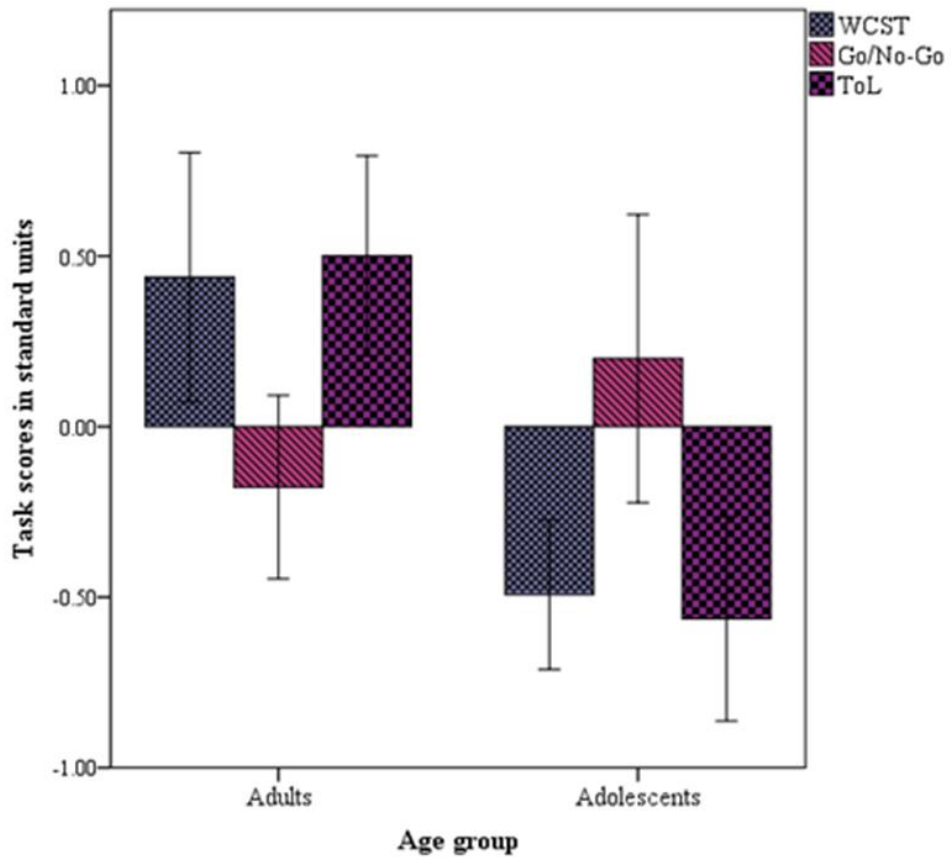
### 2.5.2 Executive Processing

#### 2.5.2.1 WCST, ToL, and Go/No-Go performance

We examined group differences in executive control using a multivariate analysis of covariance (MANCOVA). Scores on the GNG, WCST, and ToL tasks were entered as dependent variables, and participant group (adults vs. adolescents) as the independent variable. IQ was entered as the covariate. The multivariate main effect of group was significant, ( $F(3, 63) = .746, p < .001, \eta^2 = 0.26$ ), with adults demonstrating better executive processing abilities relative to adolescents (see Figure 2.4.).

Inspection of follow-up ANOVAs revealed a significant main effect of group on the WCST ( $F(1, 65) = 5.46, p = .023, \eta^2 = 0.08$ ), with adults ( $M = 32.92, SD = 17.76$ ) achieving higher set-shifting scores relative to adolescents ( $M = 17.63, SD = 9.99$ ). There was also a main effect of group on ToL scores, ( $F(1, 65) = 11.29, p = .001, \eta^2 = 0.15$ ), with adults ( $M = 16.47, SD = 3.39$ ) demonstrating better planning performance than adolescents ( $M = 12.31, SD = 3.25$ ). The main effect of group on response inhibition, ( $F(1, 65) = 4.49, p = .038, \eta^2 = 0.07$ ) was also significant. Findings revealed fewer commission errors on the GNG test for adults ( $M = 12.89, SD = 5.05$ ) than adolescents ( $M = 15.28, SD = 7.43$ ). Finally, the covariate, IQ, revealed no significant effect in the model (WCST:  $F(1, 65) = 2.52, p = .117$ ; ToL:  $F(1, 65) = .89, p = .350$ ; GNG:  $F(1, 65) = 2.00, p$

= .162). Taken together, these results provide support for the hypothesis that adolescents would demonstrate impairments on tasks tapping executive control (H5).



**Figure 2.5 Mean scores on measures of executive control for adults and adolescents.**

*Error bars represent standard errors. Graph is based on standardized dependent variables*

### 2.5.2.2 OMO Performance

Due to time limitations, data from the OMO task could not be included in the current chapter. However, analysis will be completed and incorporated into the manuscript submitted for publication.

### 2.5.2.3 Working memory performance

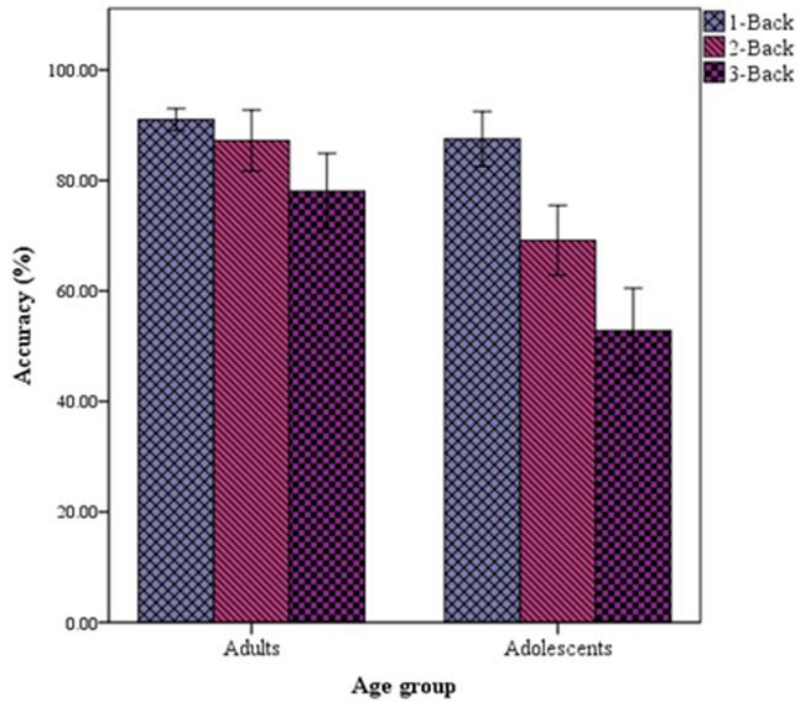
To further test hypothesis H5, a 3 (N-Back block type: '1-back', '2-back', and '3-back') x 2 (Group: Adult and Adolescent) mixed model ANCOVA was conducted on WM accuracy data, with IQ entered as the covariate. Mean percentage of accuracy was calculated across all levels for each group (see Figure 2.6).

There was a marginally significant main effect of Block-Type (Greenhouse-Geisser corrected  $F(1.75, 113.97) = 3.15, p = .053, \eta^2 = .05$ ). Post-hoc pairwise comparisons (Bonferroni corrected) indicated that percentage of accuracy was lower on the 3-back relative to 1-back (mean difference = 23.67,  $p < .001$ ) trials, and 2-back (mean difference = 12.67,  $p < .001$ ) trials. Percentage of accuracy was also found to be lower on 2-back relative to 1-back (mean difference = 11.00,  $p < .001$ ) trials.

A main effect of group was observed ( $F(1, 65) = 6.79, p = .011, \eta^2 = .10$ ), such that adolescents were less accurate overall compared to adults. There was also a significant interaction between Block-Type and Group ( $F(2, 130) = 4.54, p = .016, \eta^2 = .07$ ). This suggests that percentage of accuracy on 1-, 2-, and 3-back conditions differed for adults and adolescents. To investigate this interaction, ANCOVAs were conducted separately for adults and adolescents on percentage of accuracy. For adults, it was found that percentage of accuracy was lower for the 3-back than the 1-back (mean difference = 12.96,  $p = .001$ ) and 2-back (mean difference = 9.17,  $p = .003$ ) conditions. The remaining comparison between the 1- and 2-back conditions was non-significant (mean difference = 3.80,  $p = .135$ ). For the adolescents, accuracy scores on the 3-back condition were lower than in the 1-back (mean difference = 34.69,  $p < .001$ ) and 2-back (mean difference = 16.35,  $p < .001$ ) conditions. Accuracy scores were also found to be lower on the 2-back relative to the 1-back condition (mean difference = 18.33,  $p < .001$ ). These findings suggest that adolescents are more vulnerable to the negative effects of increasing cognitive load than adults.



Last, the covariate, IQ, was significantly related to accuracy on the N-Back ( $F(1, 65) = 4.38, p = .040, \eta^2 = .06$ ), suggesting that along with age, general cognitive ability also impacts working memory performance.



**Figure 2.6 Mean percentage of accuracy for adults and adolescents as a function of increasing cognitive load.**

*Error bars represent standard errors.*

Power analysis conducted using G\*Power (version 3.0 Faul, Erdfelder, Lang, & Buchner, 2007) indicated that for an effect size of approximately  $\eta^2 0.10$  or greater, this study had sufficient power. However, for the smallest effects that we observed ( $\eta^2 0.07$ ), a minimum of 104 participants would have been necessary to detect effects with 95% power ( $\alpha = .05$ ). As such, group differences which failed to reach statistical significance may reflect the study being underpowered.

### 2.5.3 Correlational analyses

Bivariate correlation coefficients for all variables are presented in Table 2.2. In line with our hypotheses, all RERT error scores were negatively correlated with MASC performance. With the exception of happy errors, a similar pattern emerged between RERT and EYES scores. Errors in recognising happy, fearful, angry, and sad faces were negatively associated with scores on the WCST. In addition, higher ToL performance was associated with lower errors in recognising expressions of fear, disgust, anger, and happiness. However, the negative correlations between WCST and disgust errors, and ToL and sad errors did not reach statistical significance. Analysis also revealed significant associations between working memory performance and RERT errors. Specifically, findings showed that higher accuracy across all three levels of the N-Back task were negatively associated with errors in identifying expressions of fear and anger. Accuracy on the 2- and 3-back were negatively related to errors in recognising happy and sad faces, but not with accuracy on the 1-back. Whilst percentage of accuracy on the 3-back was inversely related to errors in disgust recognition, associations with 1- and 2-back performance did not reach statistical significance. Furthermore, analysis returned non-significant associations between RERT errors and GNG performance across all emotions.

As predicted, significant associations were observed between executive processing and ToM ability. Findings showed that WCST scores were positively related to performance on the MASC and EYES tasks. MASC performance was positively related to accuracy scores across all three levels of the N-Back task, but not with EYES performance. Similarly, ToL performance was positively related to naturalistic ToM performance, but not with the static EYES test, and the associations between commission errors on the GNG task and ToM performance did not reach statistical significance. With the exception of a negative correlation between SAM performance and sad errors, no statistically significant associations were found between SAM scores and measures of ToM ability, facial affect recognition, and executive processing. Last, a positive association was observed between age and IQ, and both variables were negatively related to error rates across all RERT emotions, and positively associated with ToM ability and multiple domains of executive control (i.e., working memory, cognitive flexibility, and planning). However, neither age nor IQ were significantly related with SAM and GNG

performance. The current sample size yielded adequate statistical power to detect moderate to large (Cohen, 1988) effects (power=.95), using two-tailed tests with alpha set at .05.

**Table 2-2 Correlations between tasks measuring basic emotion recognition, theory of mind, and executive functioning.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. RERT Fear															
2. RERT Anger	.581 <i>p</i> < .001														
3. RERT Disgust	.379 <i>p</i> = .001	.343 <i>p</i> = .003													
4. RERT Sad	.494 <i>p</i> < .001	.446 <i>p</i> < .001	.174 <i>p</i> = .144												
5. RERT Happy	.515 <i>p</i> < .001	.457 <i>p</i> < .001	.411 <i>p</i> < .001	.468 <i>p</i> < .001											
6. EYES	-.374 <i>p</i> < .001	-.276 <i>p</i> = .019	-.262 <i>p</i> = .026	-.355 <i>p</i> = .002	-.211 <i>p</i> = .076										
7. MASC	-.378 <i>p</i> = .001	-.474 <i>p</i> < .001	-.310 <i>p</i> = .008	-.503 <i>p</i> < .001	-.293 <i>p</i> = .013	.270 <i>p</i> = .022									
8. SAM	-.121 <i>p</i> = .310	-.114 <i>p</i> = .341	.028 <i>p</i> = .817	-.238 <i>p</i> = .044	.025 <i>p</i> = .833	.085 <i>p</i> = .476	-.059 <i>p</i> = .620								
9. WCST	-.453 <i>p</i> < .001	-.441 <i>p</i> < .001	-.245 <i>p</i> = .044	-.213 <i>p</i> = .082	-.271 <i>p</i> = .025	.401 <i>p</i> = .001	.461 <i>p</i> < .001	.002 <i>p</i> = .987							
10. ToL	-.497 <i>p</i> < .001	-.442 <i>p</i> < .001	-.308 <i>p</i> = .011	-.210 <i>p</i> = .086	-.347 <i>p</i> = .004	.203 <i>p</i> = .097	.348 <i>p</i> = .004	-.011 <i>p</i> = .928	.415 <i>p</i> < .001						
11. GNG	.054 <i>p</i> = .664	.106 <i>p</i> = .389	.089 <i>p</i> = .473	.118 <i>p</i> = .340	.002 <i>p</i> = .985	.022 <i>p</i> = .860	-.153 <i>p</i> = .212	.009 <i>p</i> = .944	.024 <i>p</i> = .845	.085 <i>p</i> = .490					
12. 1-Back	-.272 <i>p</i> = .025	-.280 <i>p</i> = .021	-.032 <i>p</i> = .798	-.185 <i>p</i> = .130	-.107 <i>p</i> = .385	-.020 <i>p</i> = .870	.268 <i>p</i> = .027	-.127 <i>p</i> = .303	.120 <i>p</i> = .330	.028 <i>p</i> = .344	-.203 <i>p</i> = .097				
13. 2-Back	-.474 <i>p</i> < .001	-.315 <i>p</i> = .009	-.256 <i>p</i> = .056	-.442 <i>p</i> < .001	-.340 <i>p</i> = .005	.099 <i>p</i> = .424	.341 <i>p</i> = .004	-.041 <i>p</i> = .743	.373 <i>p</i> = .002	.359 <i>p</i> = .003	-.288 <i>p</i> = .017	.474 <i>p</i> < .001			
14. 3-Back	-.364 <i>p</i> = .002	-.297 <i>p</i> = .014	-.261 <i>p</i> = .032	-.427 <i>p</i> < .001	-.319 <i>p</i> = .008	.043 <i>p</i> = .727	.483 <i>p</i> < .001	-.014 <i>p</i> = .907	.442 <i>p</i> < .001	.519 <i>p</i> < .001	.039 <i>p</i> = .752	.268 <i>p</i> = .027	.695 <i>p</i> < .001		
15. Age	-.443 <i>p</i> < .001	-.393 <i>p</i> = .001	-.272 <i>p</i> = .021	-.476 <i>p</i> < .001	-.266 <i>p</i> = .024	.250 <i>p</i> = .034	.486 <i>p</i> < .001	.039 <i>p</i> = .745	.310 <i>p</i> = .010	.439 <i>p</i> < .001	-.163 <i>p</i> = .184	.214 <i>p</i> = .080	.435 <i>p</i> < .001	.454 <i>p</i> < .001	
16. IQ	-.469 <i>p</i> < .001	-.371 <i>p</i> = .001	-.261 <i>p</i> = .027	-.523 <i>p</i> < .001	-.320 <i>p</i> = .006	.265 <i>p</i> = .025	.462 <i>p</i> < .001	.173 <i>p</i> = .145	.430 <i>p</i> < .001	.417 <i>p</i> < .001	.010 <i>p</i> = .937	.234 <i>p</i> = .055	.426 <i>p</i> < .001	.491 <i>p</i> < .001	.576 <i>p</i> < .001

*Note.* RERT: Rapid Emotion Recognition Test; EYES: Reading the Mind from the EYES Test; MASC: Movie for the Assessment of Social Cognition; SAM: Self-Assessment Manikin task; WCST: Wisconsin Card-Sort Test; ToL: Tower of London; GNG: Go/No-Go.

## 2.6 General Discussion

A large body of research suggests that the prefrontal cortex and its related functions, such as social cognition and executive control, follow a protracted course of maturation that extends into the third decade of life. Despite increasing research on the development of higher-order cognition, little attention has been given to the age-related changes in these processes between middle adolescence and young adulthood.

The present study addressed this gap in the literature by providing a comprehensive assessment of social and executive functions in typically developing young adults (19-22) and adolescents (16-17). This is the first study simultaneously to examine the late developmental trajectory of facial affect recognition, empathic processing, and executive function within these age groups. Overall, these findings replicate and extend previous research by showing evidence of age-related improvements in multiple domains of social cognition and executive control, and appear consistent with studies suggesting a prolonged developmental time course for the frontal networks supporting higher-level processing. The results from this study also demonstrate strong interrelationships between several aspects of higher-order abilities, indicating a meaningful association between social and non-social cognitive processes.

### 2.6.1 *Facial affect recognition*

Glimpsing a face, even very briefly, can provide a wealth of information (e.g., age, gender, and emotional state) relevant to guiding our response in a range of social contexts (Paller, Ranganath, et al., 2003; Zebrowitz, 2006). Therefore, the ability to read others' internal states from facial expressions in a rapid and accurate manner is of paramount importance for successful communication and adaptive social behaviour.

To date, behavioural investigations suggest that facial affect recognition continues to develop between preadolescence and adulthood. For instance, findings have shown that in comparison to adults, adolescents are less sensitive to subtle changes in the intensity of negative emotions, such as fear and anger (e.g., Thomas et al., 2007). Findings from the

present study appear consistent with these results and extend them by demonstrating greater difficulties in the recognition of most basic emotions for adolescents relative to young adults. In particular, adolescents were found to be less accurate at identifying expressions of fear, followed by anger, sadness, and disgust. Consequently, the current results provide evidence that processing facial expressions of emotion continues to improve between middle adolescence to young adulthood.

These data contradict previous reports of facial affect recognition reaching stability by 15 years of age (McGivern et al., 2002), and, instead, converge with Thomas et al.'s (2007) findings showing marked improvements in affect processing between adolescence and adulthood. Of note, these results demonstrate significant differences in affect recognition over a relatively short period of development. For example, whilst Thomas et al., recruited a broader range of adults ( $M= 39.2$ ; range: 25-50), the present study focused on a much younger group ( $M= 19.36$ ; range: 19-22) to identify whether significant changes in the ability to read facial expressions occurred between adolescence and the early stages of adulthood. Thus, our data suggest that emotion recognition continues to develop beyond the mid-to-later stages of adolescence. However, future research would benefit from including older comparison samples in order to identify at which point these abilities reach adult levels of maturity.

The finding that adolescents were less accurate in identifying basic negative emotions compared to adults suggests their neural underpinnings have not yet reached full maturity. These data fit in with neurophysiological research demonstrating a prolonged course of development for the frontal circuitry supporting facial affect recognition. Numerous studies indicate rapid maturation of the prefrontal regions during adolescence (Casey et al., 2000; Giedd et al., 1999; Spear, 2000), with substantial changes occurring well into the third decade of life (Giedd et al., 2004). Therefore, the advanced emotion processing skills displayed by young adults may reflect a more refined and efficient neural system underlying affect recognition.

### 2.6.2 *Empathic Processing*

Both cognitive and affective empathy are fundamental components of adaptive social behaviour. While some studies suggest a prolonged developmental trajectory for

mental-state reasoning, the normative progression of affective empathy throughout the later stages of adolescence remains largely under-examined. The present study addressed this gap in research by employing a series of tasks tapping both domains of empathic processing in typically developing adolescents and adults.

As hypothesised, findings revealed evidence of age-related improvements in naturalistic and static mentalising ability between middle adolescence and early adulthood. Findings showed that in comparison to adults, adolescents experienced greater difficulties in attributing mental states to movie characters and pictures of eyes. This effect was stronger for the naturalistic ToM task, suggesting that the MASC is a more sensitive measure of mental-state reasoning, relative to the static EYES test. Importantly, this finding shows that along with capturing ToM deficits in clinical populations (e.g., Dziobek et al., 2006; Lahera et al., 2014; Montag et al., 2011), the MASC is also able to detect age-related changes in mentalising ability during typical development.

The observed difference between the two measures does not come as a surprise. Whereas the EYES test involves decoding mental states from still images of the eye region, the MASC is a more dynamic measure of ToM and requires participants to read social cues from multiple modalities in an everyday context. Therefore, optimum performance on the MASC is likely to entail multiple cognitive processes allowing one to adjust to varying situational demands and to suppress one's own perspective in order to identify another person's internal state. Given that the neural circuitry supporting these higher-order abilities matures during the third decade of life, it stands to reason that adolescents may encounter greater difficulties in situations necessitating more complex forms of mental state reasoning. In contrast, static measures of ToM are unlikely to require a similar level of higher-order processing and, consequently, may be less sensitive to the critical developmental changes in mentalising ability occurring between mid-adolescence and young adulthood.

The finding that mental state reasoning improves with age fits in with previous behavioural work (Dumontheil et al., 2010) suggesting continued ToM development between the later stages of adolescence and adulthood. Although the present study is unable to determine the underpinnings of this late developmental course, our data appear consistent with neuroimaging research demonstrating that brain regions supporting

mentalising ability undergo profound structural (e.g., Giedd et al., 1999) and functional (e.g., Blakemore, 2008) changes during adolescence.

However, it is worth noting that these data contradict recent reports showing stabilised mental state reasoning between the mid-to later stages of adolescence (Bosco et al., 2014; Taylor et al., 2013). One account for the apparent lack of convergence may lie in the assessment techniques employed. For instance, whilst Bosco et al. (2014) examined mentalising ability using a semi-structured interview, the present study utilised a set of behavioural tasks to assess the presence of age-related changes in ToM performance. Therefore, it is quite possible that the behavioural measures employed in the present study are better able to capture late-occurring developmental changes in mentalising ability.

Indeed, task differences provide a plausible explanation for the discrepancy with Bosco et al's, (2014) data. Nonetheless, given that Taylor and colleagues (2013) also examined mentalising skills via the EYES and MASC tasks, this account does not extend to the lack of age effects reported in their study. One explanation that may shed light on this result is the use of restricted age groups. In order to obtain more refined assessment of ToM development, Taylor et al., compared performance across groups of 17, 18, and 19 year olds. However, as mentioned previously, the neural structures underlying ToM ability follow a protracted course of maturation, which goes beyond adolescence and extends into the early stages of adulthood. Consequently, focusing on narrow age groups not only reduces the likelihood of detecting age-related advancements in mental-state attribution, but also limits our understanding of ToM development in normative samples. By examining performance differences over a wider age range, the present study has uncovered age-associated improvements in mentalising ability through which it provides a more comprehensive profile of ToM development between middle adolescence and young adulthood.

In contrast to ToM, there was no evidence of age-related changes in affective empathy, with adults and adolescents demonstrating comparable performance on the SAM task. These findings suggest that whilst age-related changes in mentalising ability extends into the early stages of adulthood, the capacity to resonate with others affective experiences becomes established much earlier. Taken together, these data appear consistent with previous reports establishing mental state reasoning and affective resonance as separate forms of empathy, with interacting, yet partially distinct, neural



substrates, and diverse developmental trajectories (Decety, 2011; Decety & Michalska, 2010).

### *2.6.3 Executive Processing*

Executive control is critical to everyday functioning and forms the cornerstone of goal-directed adaptive behaviour. Similar to facial affect recognition and ToM, these cognitive processes are thought to follow an extended time course, with development going beyond adolescence and extending into early adulthood. While the normative development of executive control has been subject to much research, studies examining these processes during the later stages of adolescence are comparatively few. To help rectify this gap in the literature, multiple domains of executive control were examined in typically developing adults and adolescents. In line with the study predictions (Hypothesis H5), there were age-related differences across all measures of executive processing between middle adolescence and early adulthood. Findings showed that in comparison to young adults, adolescents display lower efficiency scores on the WCST, higher commission errors on the Go/No-Go, reduced planning ability on the ToL task, and poorer WM performance on the N-Back. These findings accord well with previous behavioural work documenting age-associated improvements on tasks assessing planning ability (Albert & Steinberg, 2011; De Luca et al., 2003; Guevera et al., 2012; Huizinga et al., 2006; Luciana et al., 2009), set-shifting (Huizinga et al., 2006), response inhibition (Huizinga et al., 2006; Johnstone et al., 2005; Tamm et al., 2002), and working memory (Anderson, et al., 2001). Of note, the obtained results also converge with existing imaging data suggesting that the neural architecture supporting these skills follows a prolonged developmental trajectory and becomes more fine-tuned with age (Casey et al., 2000; Giedd et al., 1999; Giedd et al., 2004; Spear, 2000).

In contrast, these findings appear to contradict reports suggesting that certain domains of executive control reach adult-level maturity by middle adolescence (Anderson et al., 2001; Taylor et al., 2013). Once again, the inconsistencies may be explained by the methodological differences between the studies. For instance, whilst Taylor et al. used a set of manually administered executive function tasks, the computerised measures employed in the present study were similar to those showing developmental differences in

higher-order cognition (e.g., Go/No-Go, Tamm et al., 2002; WCST & ToL, Huizinga et al., 2006). As such, comparison between the two studies is less straightforward, given that the tasks employed may have placed differential demands on executive processing. Furthermore, Taylor and colleagues focused on a restricted age-range, which may have reduced the likelihood of detecting late-occurring advancements in executive functioning. Thus, by examining these processes over a broader range of adults and adolescents, the present study has identified age-related improvements in higher-order cognition, and provides a more comprehensive account of executive control development between middle adolescence and the early stages of adulthood.

#### *2.6.4 Interrelationships between social cognition and executive control*

Several studies have documented a meaningful relationship between social cognition and executive control (e.g., Dumontheil et al, 2010; Pellicano, 2007). Consistent with these results, the present study revealed significant associations between facial affect recognition, ToM performance, and executive processing. For instance, MASC scores were positively correlated with set-shifting, planning ability, and working memory performance. However, the negative association between MASC performance and commission errors on the GNG task did not reach significance levels. Performance on the static EYES test was also positively related to set-shifting ability, but associations between planning performance, Working memory, and response inhibition were non-significant.

With respect to facial affect recognition, analysis revealed significant associations with mentalising performance and executive processing. For instance, higher scores on the naturalistic MASC task were negatively related to RERT errors across all basic emotions. A similar pattern emerged for the static EYES test, although the negative association between happy errors fell short of significance. These findings indicate a meaningful association between facial affect recognition and the ability accurately infer complex mental states.

With the exception of sadness, higher set-shifting scores were negatively related to errors in recognising all basic emotions. Planning ability was also associated with better recognition of faces depicting fear, anger, happiness, and disgust, but not with expressions

of sadness. Whilst working memory performance was related to lower errors in identifying all basic emotions, these associations varied as a function of cognitive load. Namely, findings showed that recognising expressions of fear and anger were related to better performance across all three levels of cognitive load (i.e., 1-, 2-, and 3-back trials). Recognition of sadness and happiness was also related to better working memory performance, but only on 2- and 3-back trials. Last, recognising facial expressions of disgust was only related to accuracy scores on 3-back trials. In contrast, no significant association was found between response inhibition and facial affect processing. Together, these findings indicate a significant overlap between affect processing, ToM, and executive control.

Apart from sad errors, facial affect recognition was unrelated to scores on the SAM-Faces task. This finding is somewhat surprising given that emotion recognition is critical to generating appropriate affective responses to others emotional states (Blair, 2008). One possible explanation for this result may lie in the differing levels of complexity between the tasks. For instance, whilst the RERT requires participants to identify emotions in rapidly presented facial stimuli (i.e., 100ms), the SAM-Faces task is a self-paced assessment tool, where all images are presented on the screen until the participant rates their affect. Consequently, given the time-limited nature of the RERT, identifying emotions from the stimuli presented in this task is likely to be significantly more complex than identifying and responding to the affective stimuli featured in the SAM-Faces task.

In terms of executive control, none of the sub-domains of this construct were related to affective empathy. Of note, these results also suggest that while certain measures of executive control share some variance, they can capture different aspects of higher-order cognition.

### *2.6.5 Limitations and Future Directions*

Some limitations of this research should be noted. A large proportion of the sample consisted of female participants, leading to a significant gender imbalance in our sample. This is due to the study recruitment primarily relying on Psychology students (undergraduate and A-level), where there is an evident female bias. While analysis revealed no confounding by gender, future investigations would benefit from recruiting an

equal number of male and female participants in order to help identify potential sex-differences in social cognition and executive function development.

Another limitation concerns the significant group differences in general cognitive ability. Whilst statistically controlled for in all analyses, performance differences between the adult and adolescent groups may still have been influenced by IQ. Future investigations should therefore aim to replicate these findings in adult and adolescent groups closely matched on general cognitive ability. This control will help researchers draw more firm conclusions regarding the development of social cognition and executive control between the later stages of adolescence and young adulthood.

Furthermore, the number of measures used, and as a result, comparisons performed in the current study may have increased the risk of type 1 errors (i.e., false positives). Correcting for multiple testing using Bonferroni correction would help to reduce rate of type 1 errors. However, this would also increase the likelihood of false negatives, particularly given that the measures used are not statistically independent (see Table 2.2). Adjusting for multiple tests is not standard procedure within the literature and a number of studies performing a similar amount of tests to address multiple specific hypotheses have done so without applying adjustments (e.g., Dziobek et al., 2006; Lahera et al., 2014; Pellicano, 2007; Taylor et al., 2013). However, given the potential for false positives, the results presented in the thesis should be considered exploratory, and additional studies should be undertaken to replicate these findings.

Although findings showed that age-related improvements in higher-order cognition continued into the early stages of adulthood, PFC-related processes may develop beyond 22 years of age. Therefore, future research would benefit from including a sample of older adults (i.e., 25-30) in order to determine the developmental stage at which higher-order cognition reaches maturity. In addition, the tasks included in the social cognition battery were solely based on adult faces and movie characters. Future investigations should therefore incorporate age-appropriate faces and characters when assessing social cognition in adolescents. Given the increased salience of peers during this period of development, such an approach would help identify whether sensitivity to peers impacts the processing of socially relevant information.

On a related note, although naturalistic assessments provide a closer approximation of empathic processing in everyday social interactions, mental-state

reasoning and affective responses occur in the context of reciprocal communication. Consequently, it would be of particular interest to compare adults against adolescent interpersonal competence in an experimental setting. This line of investigation would also help identify whether the age-associated differences in higher-order cognition explain functioning in real-world settings.

Examining social cognition and executive function in typically developing children, adolescents, and adults via longitudinal designs may also provide critical insight into the normative progression of higher-order skills. While the findings reported in this chapter point to late-occurring changes across multiple PFC-related functions, longitudinal designs would allow researchers to obtain a more accurate profile of social and executive functioning, and provide vital information concerning the link between these constructs, including whether their sub-domains follow distinct developmental trajectories. Finally, whilst the current sample demonstrated sufficient power to detect moderate to large effects, future investigations would benefit from administering these measures to larger samples of adults and adolescents in order to increase sensitivity to detect small effects.

## **2.7 Conclusions**

To summarise, findings from the present study suggest that many aspects of higher-order cognition undergo a period of marked development between middle adolescence and the early stages of adulthood. These results are in line with neurophysiological data showing a prolonged course of maturation for the prefrontal regions underpinning social and executive processing. This is the first study simultaneously to examine the late developmental trajectory of facial affect recognition, empathic processing, and executive control in a sample of mid-adolescents and young adults. Further investigation into the development of social and executive functioning in clinical and normative populations will ultimately help delineate the key neurocognitive processes underlying adaptive behaviour.

### **3 Associations between facial affect recognition, empathic processing, executive function, and subclinical autism traits.**

### 3.1. Chapter Introduction

Chapter 2 established age-related improvements in multiple aspects of higher-order cognition. Specifically, findings show that social and executive processes undergo a period of marked development between mid-to-late adolescence and the early stages of adulthood. The aim of the present chapter was to extend the examination of higher-order processing to subclinical levels of autism traits. As previously discussed, ASD is characterised by profound difficulties in social cognition and executive control. Whilst the links between these processes have been frequently investigated in populations with autism, few studies have examined this association at the subclinical level. In addition, the contribution of alexithymia, a trait characterised by impaired interoceptive awareness and empathy, and elevated in those with ASD, is currently unclear. To address this gap in the literature, the present two-part study aimed to provide a comprehensive evaluation of these processes in a non-clinical population. Using the test battery from Chapter 2, the current chapter aimed to provide a detailed examination of the associations between empathic processing (affective empathy, static and naturalistic mentalising), executive function (planning ability, cognitive flexibility, and response inhibition), and autism symptomatology in a sample of typically developing adults and adolescents.

#### 3.1.1 *Social Cognition in ASD*

As mentioned previously, social cognition refers to an array of processes that enable one to successfully interact with others and to regulate interpersonal behaviour in an adaptive manner (Adolphs, 2003, 2009; Brothers, 1990; Frith, 2007; Frith & Frith, 2003; Green et al., 2008). Deficits in social cognition have frequently been cited as a core feature of autism spectrum disorder (ASD). The present study will focus on two key domains of social cognition: facial affect recognition and empathic functioning.

### *3.1.1.1 Facial Affect Processing in ASD*

The human face is the most important visual stimulus for social interactions (Ellis & Young, 1998; Cohen Kadosh & Johnson, 2007; Frischen et al., 2007). The ability to decode emotional expressions is integral to social performance, and serves as a vital building block for the development of more intricate social processes, such as mentalising ability and affective resonance.

Despite receiving considerable attention in autism research, the current literature on facial affect processing has yielded a mixed pattern of results. To date, numerous studies examining basic emotion recognition abilities via static images have revealed ASD-related impairments (Ashwin et al., 2006; Celani, et al, 1999; Davies, et al, 1994; Eack, et al, 2014; Wallace, Coleman, & Bailey, 2008). Moreover, rather than a global deficit in affect recognition, some studies indicate specific impairments in the processing of negatively valenced expressions, such as fear (Howard, et al, 2000), and disgust (Golan & Baron-Cohen, 2006), whilst others report deficits for multiple negative emotions (e.g., sadness, anger, fear, and disgust; Ashwin et al., 2006; Ellis & Leafhead, 1996). In contrast, however, other studies have found no significant differences between ASD and typically developing populations (Adolphs et al., 2001; Baron-Cohen et al., 1997; Castelli, 2005; Jones et al., 2011; Ozonoff et al., 1990; Tracy et al., 2011).

Many of the studies reporting typical facial affect processing in ASD have employed relatively simplistic stimuli (i.e., facial expressions at full intensity), presented for a lengthy period of time. However, in everyday social interactions, we are required to read and identify emotional expressions of varying intensities in a rapid manner (De Sonnevile et al., 2002). Thus, while high-intensity emotion processing may be intact in those with ASD, the inability to decode rapidly and accurately another person's emotional state from subtle expressions is likely to impede adaptive social behaviour, and may provide insight into the empathy and mentalising deficits characterising the disorder.

### *3.1.1.2. Empathic Processing in ASD*

Empathy is the ability to understand and resonate with the affective experiences of others (Decety & Lamm, 2006; Singer & Lamm, 2009). It plays a pivotal role in the formation of successful human relationships (Baron-Cohen & Wheelwright, 2004; Decety



& Jackson, 2006; Decety & Lamm, 2006; Dziobek, et al, 2008; Rameson, et al, 2012; Singer, 2006). Two main components contribute to empathic processing: an affective component, which allows one to share the feelings of others, and a cognitive component (also referred to as mentalizing, cognitive perspective-taking, or ToM), which involves the ability to identify and understand what another person is thinking or feeling without becoming emotionally involved (Frith, 2008; Frith & Frith, 2003; Premack & Woodruff, 1978; Shamay-Tsoory, 2011; Shamay-Tsoory, Aharon-Peretz, & Perry, 2009).

Atypicalities in empathic functioning have also been cited as a core feature of ASD. Over the past few decades, a growing body of research has revealed ASD-related impairments in ToM. For instance, Baron-Cohen and Wheelwright (2004) documented lower levels of empathy for adults with ASDs using the empathy quotient (EQ), a 40-item self-report questionnaire that primarily focuses on the cognitive domain of this construct. Behavioural data from studies using static (e.g., Baron-Cohen, et al, 2001a; Baron-Cohen, et al, 1997; Baron-Cohen, Wheelwright, et al, 2001b; Dziobek et al, 2006; Lahera, et al., 2014), and more naturalistic video-based assessments of ToM (e.g., Dziobek et al., 2006; Heavey, et al, 2000; Ponnet et al., 2008) have also reported ASD-specific deficits in mental state attribution.

Conversely, results from studies examining affective empathy in ASD have been far less consistent. For instance, Minio-Paluello and colleagues (Minio-Paluello, Baron-Cohen, Avenanti, Walsh, & Aglioti, 2009) found that individuals with ASD showed no sensorimotor resonance when observing another person in pain. Findings from related investigations in ASD samples, however, indicate typical physiological responses to others' pain (Fan, Chen, Chen, Decety, & Cheng, 2014; Hadjikhani et al, 2014) and distress (Blair, 1999). In fact, Smith (2009) suggests that autism is associated with heightened levels of affective empathy, and reports of greater responsiveness to others' emotional states in children with ASD yield support for this hypothesis (Capps, Kasari, Yirmiya, & Sigman, 1993).

To date, only a small number of studies have jointly assessed the cognitive and affective components of empathy in ASD populations. For instance, using the Interpersonal Reactivity Index (Davies, 1980), Rogers and colleagues' (Rogers, Dziobek, Hassentab, Wolf, & Convit, 2007) reported reduced cognitive empathy in adults with Asperger syndrome, but found no impairments in empathic concern (a process related to

affective empathy). A later study by Dziobek et al. (2008) also revealed dissociable deficits in empathic processing. These researchers found that whilst there were no group differences on the affective domain of the Multifaceted Empathy Test, individuals with ASD exhibited clear deficits in their ability to infer another person's mental state. Studies investigating empathic processing in children with ASD also reveal a profile consistent with atypical cognitive empathy. Findings from these studies suggest that while boys with ASD experience significant difficulties in mentalization, their capacity to resonate with another person's emotional state remains intact (Jones, Happé, Gilbert, Burnett, et al., 2010; Schwenck, Mergenthaler, Keller, Zech, Salehi, & Taurines, 2012). Taken together, these studies indicate that individuals with ASD show specific difficulties in mental state attribution, rather than a global deficit in empathic processing.

Recent examinations of ASD traits in the general population yield a similar pattern of results. For example, Gökçen and colleagues (Gökçen, et al., 2014) reported poorer ToM performance in typically developing adults with elevated levels of ASD traits. In a study investigating both domains of empathic functioning, higher ASD traits were associated with atypical perspective-taking abilities on the animated triangles task, but no impairments were found on a measure examining affective responses to emotional faces (Lockwood et al., 2013). In sum, these findings suggest that even in the absence of a clinical diagnosis, individuals with higher levels of autistic-like traits may be more susceptible than the general population to ASD-related empathy deficits.

### *3.1.2 Alexithymia*

An important consideration when examining facial affect recognition and empathy processes in ASD is the high comorbidity between autism and alexithymia. Alexithymia is a subclinical condition characterized by difficulties in the ability to recognize, express, and distinguish emotional states from bodily sensations (Nemiah, et al, 1976). In recent years, studies have suggested that the affective and empathic deficits associated with autism may be a consequence of co-occurring alexithymia, rather than ASD per se (Bird, Silani, Brindley, White, Frith, & Singer, 2010; Cook et al., 2013; Silani et al., 2008), and that controlling for alexithymia reveals comparable levels of empathy (Bird & Cook, 2013) and facial affect recognition in individuals with and without ASD (Cook et al.,

2013). Nevertheless, reports from studies examining autistic individuals (Fan et al., 2013) and ASD traits in typically developing populations (Lockwood et al., 2013) showed no significant effects of alexithymia on measures of empathic processing.

### *3.1.3 Executive Function*

A further consideration in the study of empathy is its relationship with executive function, which refers to a set of higher-order cognitive mechanisms facilitating adaptive and goal-directed behaviour in a constantly changing environment (Corbett, Constantine, Hendren, Roche, & Ozonoff, 2009; Jurado & Rosselli, 2007; Lezak, 1995). Executive functions are thought to encompass several distinct, yet interrelated processes, such as planning, cognitive flexibility (or set-shifting), and response inhibition (Stuss & Knight, 2002). To date, there has been a wealth of evidence suggesting a robust link between these higher-order processes and mentalising ability. For instance, studies examining this association in typically developing children have found that better abilities in executive control were related to enhanced performance on ToM tasks, independent of intellectual functioning (Austin, Groppe, & Elsner, 2014; Carlson, Claxton, & Moses, 2013; Carlson & Moses, 2001; Carlton, Moses, & Breton, 2002; Hughes, 1998a, b; Sabbagh, Xu, Carlson, Moses, & Lee, 2006; though see Pellicano, 2007 and Perner et al., 2002). Furthermore, growing empirical evidence suggests that the positive association between executive and ToM processes goes beyond childhood, and extends into adolescence and adulthood (Apperly et al., 2009; Bull, et al, 2008; Gökçen et al., 2014; Vetter et al., 2013).

Considerable attention has also been devoted to understanding the executive function and ToM link in autistic populations. Studies have shown that along with impaired mentalisation, individuals with autism (Dawson, et al, 1998; McEvoy, et al, 1993; Pellicano, 2007; Robinson et al, 2009; for reviews see Hill, 2004 and Russo, et al, 2007), or with elevated levels of ASD traits (Christ, Kanne, & Reiersen, 2010), exhibit significant deficits in multiple domains of executive processing. In addition, results from studies assessing both executive and ToM abilities in ASD have consistently revealed a link between the two constructs, independent of age and intellectual ability (Joseph & Tager-Flusberg, 2004; Ozonoff, Pennington, & Rogers, 1991; Pellicano, 2007). Similar results have also been obtained from a sample of neurotypical adults demonstrating higher

and lower levels of ASD traits (Gökçen et al., 2014). Findings showed that adults in the high ASD trait group displayed significantly poorer performance on tasks tapping ToM and cognitive flexibility, relative to their low ASD trait counterparts. However, it is worth noting that other investigations have documented non-significant correlations between measures of ToM and executive functioning in individuals with ASD (Dziobek et al, 2006; Lahera et al, 2014).

Given the observed association and the coexistence of executive function and ToM deficits in autism, many studies have sought to establish the interrelationships between these cognitive domains in typical and atypical development. Whilst some researchers (Perner, 1997; Perner, et al., 2002) contend that intact ToM fosters executive function, stronger support has emerged for a causal effect in the opposite direction (Russell, 1997, 2002), suggesting that intact executive functioning is a prerequisite for successful ToM in individuals with (Pellicano, 2007) and without (Austin et al., 2014; Hughes, 1998b; Hughes & Ensor, 2007) ASD. Together, these findings highlight the importance of executive function skills in successful mentalization, and suggest that the ToM impairments observed in ASD may be a reflection of deficiencies in executive control.

While the executive function and ToM link has been well-documented throughout the literature, and there is some evidence of significant associations with facial affect recognition (Oerlemans et al, 2013), much less is known about its possible role in the affective domain of empathy. Some reports suggest a significant association between affective empathy and executive control processes in patients with frontotemporal dementia (Eslinger, Moore, Anderson, & Grossman, 2011). However, there is a dearth of research examining these associations in relation to ASD and typical development.

In sum, given the emerging evidence indicating a similar (though milder) pattern of difficulties among individuals with elevated levels of ASD traits, examining autism symptomatology among typically developing populations is a promising line of research, potentially offering novel information about the social and non-social features of ASDs. A key advantage of examining typically developing individuals with ASD traits is that they are more likely to be tolerant of structured testing environments in comparison to those with a clinical diagnosis. Consequently, we may be able to gain unique insights into the

autism spectrum by employing a wider range of tasks and methodologies when studying this broader population.

Of note, establishing links between social cognition and executive control in ASD could have important implications for both clinical and non-clinical ASD populations. Specifically, a detailed examination of these processes could help identify key neurocognitive mechanisms that may influence the therapeutic efficacy of social interventions. Interventions targeting the interpersonal domain typically focus on broader, more goal-oriented aspects of social interactions (enhancing general conversational skills, interpersonal relationship formation etc.) and their application to real-world settings. However, given the meaningful overlap between social and non-social domains of cognition, it may be necessary to remediate the deficits in more 'basic' neurocognitive processes, before targeting more higher-order social competencies. A multi-tier intervention strategy could, therefore, enhance positive outcomes and prove more effective in alleviating the negative consequences associated with social dysfunction in autism (e.g., peer-rejection, loneliness, and mental health difficulties; Bauminger & Kasari, 2000; Chamberlain, Kasari, & Rotheram-Fuller, 2007; Tantam, 2003). Furthermore, given that the autism spectrum extends into the general population, typically developing individuals with elevated levels of ASD traits may also benefit from programmes supporting adaptive social functioning. However, a necessary prerequisite for devising such interventions is furthering our understanding of the neurocognitive processes associated with social impairments in ASD.

### **3.2 The Present Study**

The present two-part study aimed to provide a comprehensive examination of the facial affect processing, empathy, executive function, and ASD trait link in a sample of typically developing adults and adolescents. The first part of the study employed a more demanding time-limited measure of facial affect recognition (Rapid Emotion Recognition Test, RERT; Lockwood & Gökçen, *in progress*), and investigated multiple domains of empathic processing by utilising ecologically valid measures of cognitive (Movie for the Assessment of Social Cognition, MASC; Dziobek et al., 2006) and affective (SAM; Seara-Cardoso, Craig, Roiser, McCrory, & Viding, 2012) empathy. The Reading the Mind

from the Eyes Test (EYES; Baron-Cohen et al., 2001a) was also administered as a static index of ToM to assess its sensitivity to impairment against a more naturalistic, video-based measure (i.e., MASC). The second study examined associations between affect recognition, empathic processing, ASD traits, and the executive domains of response inhibition, planning, and cognitive flexibility. This study also assessed the relationship between these higher-order cognitive processes and subclinical features of autism. Across both studies, the potential contribution of alexithymia to performance on measures of cognitive and affective empathy was examined, as well as its association with multiple aspects of executive control.

Based on the evidence outlined above, individuals with higher ASD traits were predicted to demonstrate poorer facial affect recognition, specifically to expressions depicting negative valence (H1). With regards to empathic processing, it was hypothesized that individuals with higher ASD traits would demonstrate poorer performance on measures of cognitive, but not affective, empathy (H2), and this impairment was expected to be more pronounced on the MASC task relative to the EYES (H3).

In addition to a unique contribution by subclinical autism traits, a positive relationship between measures of executive control and the cognitive, but not the affective, domain of empathy was hypothesised (H4). A significant overlap between facial affect processing and executive control was also predicted (H5). Furthermore, individuals with higher levels of ASD traits were predicted to demonstrate poorer performance on tasks assessing executive control (H6).

With respect to alexithymia, higher levels of this trait have been shown to predict deficits in both cognitive (Moriguchi, Ohnishi, Lane, Maeda, Mori, Nemoto, et al., 2006) and affective (Lockwood et al., 2013) empathy, as well as impairments in facial affect recognition (Cook et al., 2013), and executive functioning (Koven & Thomas, 2010). Consequently, it was hypothesised that elevated levels of alexithymia would be related to poorer performance on measures of cognitive and affective empathy (H7), as well as on measures indexing facial affect recognition (H8) and executive control (H9). Finally, in light of the protracted development of empathic and executive processes over the period of preadolescence and adulthood (Decety, 2010; Dumontheil, et al., 2010), and of the association of these processes with general cognitive ability (Pellicano, 2007), IQ and age were incorporated into the design as control variables.

### **3.3 Method: Study 1**

#### *3.3.1 Participants*

One-hundred-and-twenty-four healthy adults and adolescents were recruited through a university subject pool and a London-based Sixth-Form college. Two participants were excluded from the analyses because they were missing data on one of the experimental tasks, and one because he or she scored above the clinical cut-off point (i.e., 32+) on the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001). This left a final sample of 121 participants (15% male) aged 16-35 ( $M= 18.43$ ,  $SD= 1.93$ ), with IQs between 72 and 129 ( $M= 102.02$ ,  $SD= 11.55$ ).

#### *3.3.2 Measures*

##### *3.3.2.1. ASD Traits*

The AQ (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001c) is a 50-item self-report questionnaire designed to assess autism traits in both clinical and community samples. It comprises five subscales (social skills, attention switching, attention to detail, imagination, and communication), and requires respondents to indicate whether they ‘strongly agree’, ‘slightly agree’, ‘slightly disagree’, or ‘strongly disagree’ with each statement. Responses in the ‘autistic’ direction receive 1 point, whilst ‘non-autistic’ responses receive 0 points. Total scores range from 0 to 50, with higher scores indicating greater levels of autism symptomatology. Psychometric examination of the AQ has revealed good test–retest reliability and moderate to high internal consistency (Baron-Cohen et al., 2001c; Cronbach’s alpha 0.67 in the present study), as well as good discriminative validity (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005).

### 3.3.2.2. *Alexithymia*

Alexithymic traits were assessed using the Toronto Alexithymia Scale (TAS; Bagby, Parker, & Taylor, 1994), a 20-item instrument comprising three dimensions: difficulty identifying feelings, difficulty describing feelings, and externally oriented thinking. Each item is responded to on a five-point Likert scale ranging from “strongly disagree” to “strongly agree”. Total scores vary from 20 to 100, with higher scores indicating a greater degree of alexithymia. The TAS has generally shown robust psychometric properties (Bagby, Taylor, Quilty, & Parker, 2007; Parker, Taylor, & Bagby, 2003; Cronbach’s alpha 0.81 in the present study).

### 3.3.2.3. *Facial Affect Processing*

Facial emotion recognition was assessed using the computerised Rapid Emotion Recognition Test (RERT; Lockwood & Gökçen, in progress). Facial stimuli were derived from Karolinska Directed Emotional Faces battery (Lundqvist, Flykt & Öhman, 1998), and the task was programmed using JavaScript and presented in Google Chrome. The RERT requires participants to focus on a centrally located fixation cross for 500ms. Subsequently, an image of a male or female face is presented for 100ms. Each face depicts one of five basic emotions (fear, anger, disgust, happy, or sad), or a neutral expression. The image is then backward masked for 50ms and the participants must then select which emotion the face displayed from six options. The next trial began immediately after the participants’ response, or after 4000ms, if no response was made. In total, there are 144 trials (50% male), with 24 trials for each type of emotion. The average completion time of the RERT is 10 minutes. A percentage of error rate is calculated for each emotion, with higher rates indicating greater difficulties in emotion recognition.

### 3.3.2.4. *Empathic Functioning*

*Static Theory of Mind.* The Reading the Mind from the Eyes Test (EYES; Baron-Cohen, Wheelwright, Hill, et al., 2001) is a widely used measure of theory of mind ability. It assesses the capacity to understand and infer the mental state of others from static images depicting the eye region of the face. Based on this visual information alone,



respondents are required to choose which of four mental state terms (one target word and three foils) correctly depicts what the person in the picture is thinking or feeling. Two variants of this test were administered: the revised 36-item adult version (Baron-Cohen, Wheelwright, Hill, et al., 2001; completed by all participants recruited via the subject pool) and the 28-item child version (completed by all participants recruited via a Sixth-Form college).

The adult EYES comprises complex mental state terms (e.g., ‘pensive’, ‘playful’, and ‘elated’), whilst the child version consists of simpler descriptors (e.g., ‘happy’, ‘sad’, and ‘scared’). Participants completing the adult version were informed that they could request an explanation of the descriptor meanings and could also consult a glossary, if they were unsure of any of the words used. One point was assigned for all correct answers and a percentage of accuracy score was calculated for each participant.

*Naturalistic ToM.* The Movie for the Assessment of Social Cognition (MASC; Dziobek et al., 2006) is a naturalistic video-based mentalising task that approximates the demands of real-life social situations. It involves watching a 15-minute movie about four characters spending an evening together and answering questions concerning their mental states. The film incorporates themes about peer and romantic relationships, and requires participants to process information from visual (e.g., facial expressions and eye gaze), auditory (e.g., prosody), and verbal (e.g., content of language) channels. The film is paused at 45 points, and participants are asked to respond to questions relating to the characters’ thoughts, feelings, and intentions (e.g., “What is Cliff feeling?,” “What is Betty thinking?,” “Why is Michael doing this?”). Answer options are presented in a multi-choice format comprising four response options: (1) hypermentalising (e.g., “she is exasperated about Michael coming on too strong”), (2) under/reduced mentalising (e.g., “she is pleased about his compliment”), (3) no mentalising (e.g., “her hair does not look that nice”), and (4) accurate mentalising (e.g., “she is flattered but somewhat taken by surprise”). Total scores vary between 0-45, with higher values indicating greater mentalising ability. Adequate psychometric properties have been reported for the MASC (Dziobek et al., 2006), with the task successfully distinguishing between healthy participants and individuals diagnosed with Asperger syndrome (Dziobek et al., 2006),

schizophrenia (Montag et al., 2011), and borderline personality disorder (Preißler, et al., 2010; Sharp, Pane, Ha, Venta, Patel, Sturek, et al., 2011).

*Affective Empathy.* The Self-Assessment Manikin Faces Task (SAM-Faces) is an ecologically valid index of affective empathy (Lockwood et al., 2013; Seara-Cardoso et al., 2012; Seara-Cardoso, Dolberg, Neumann, Roiser, & Viding, 2013). It requires participants to rate their own emotional response to pictures of faces displaying sad, fearful, angry, happy, or neutral expressions. Participants respond to each image using a 9-point valence scale, ranging from a low-spirited manikin ('1') to a cheerful one ('9'), with a neutral manikin in the middle ('5'). The sequence of images was randomized for each participant and the ratings for sadness, fear, and anger were reverse-scored so that higher scores reflected greater distress when viewing others' negative emotions. These variables were subsequently transformed into z-scores and a composite score was created along with the ratings for happy expressions. This measure is thought to tap into the affective empathy construct, as it not only examines participants' vicarious response to emotional stimuli, but also includes aspects of self-awareness (evaluating own emotional response) and of self/other distinction (evaluating how the stimulus makes them feel; [Seara-Cardoso et al., 2012; Seara-Cardoso et al., 2013]).

#### 3.3.2.5. *General Cognitive Ability*

The full-scale IQ of each participant was measured using the two-subset form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999).

### 3.3.3 *Procedure*

The study protocol was granted ethical approval from the university Research Ethics Committee, and written informed consent was obtained from all participants as well as from the parents or guardians of adolescents. A series of tasks assessing social cognitive functioning were administered as part of a wider battery of measures. Each participant was tested individually for approximately 2 hours in a quiet, dimly lit room. All tasks were presented in randomised order and instructions were provided at the beginning of each

test. Participants were allowed to take short rest breaks between the tasks as needed. At end of the test battery, an estimate of general intellectual functioning was obtained using the two-subtest form of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999).

### **3.4 Results and Discussion**

#### *3.4.1 Preliminary Analysis*

The study variables were visually inspected for normal distribution via QQ plots. Minor to moderate deviations from normality were detected for the following variables: MASC, EYES, RERT Happy, and RERT Sad. All remaining variables revealed approximate normality. Slight violations to the assumption of normality are unlikely to cause a major problem, provided that the sample contains a sufficient number of observations ( $> 30$  or  $40$ ; central limit theorem, Field, 2002). Thus, given the relatively large sample size ( $n = 121$ ) in the present study, the use of parametric tests was deemed suitable.

#### *3.4.2 Correlational analyses*

The means, standard deviations, and bivariate correlation coefficients for all variables can be seen in Table 3.1 As predicted, ASD traits showed a negative correlation with MASC ( $r = -.404, p < .001$ ) and EYES ( $r = -.218, p = .017$ ) performance, and positive correlations with RERT errors on trials depicting sad ( $r = .224, p = .014$ ) and angry ( $r = .210, p = .021$ ) faces. Conversely, there was no statistically significant association between ASD traits and SAM scores ( $r = .023, p = .804$ ). Alexithymia was negatively associated with MASC ( $r = -.402, p < .001$ ) and EYES scores ( $r = -.303, p = .001$ ), and positively associated with ASD traits ( $r = .437, p < .001$ ) and errors in recognising expressions of fear, sadness and anger (Fear:  $r = .250, p = .006$ ; Anger:  $r = .243, p = .007$ ; Anger:  $r = .223, p = .014$ ). The negative association between TAS scores and SAM performance did not reach statistical significance ( $r = -.106, p = .249$ ). Whilst performance on the MASC and EYES tasks was positively correlated ( $r = .288, p = .001$ ), neither of these ToM measures were correlated with SAM performance, although EYES

performance revealed a trend towards significance (MASC:  $r = -.036, p = .692$ ; EYES:  $r = .158, p = .083$ ). With regards to RERT scores, analysis revealed an inverse relationship between facial affect recognition and MASC scores (Happy:  $r = -.306, p = .001$ ; Sad:  $r = -.464, p < .001$ ; Angry:  $r = -.383, p < .001$ ; Disgust:  $r = -.266, p = .003$ ; Fear:  $r = -.380, p < .001$ ). With the exception of happy expressions, a similar, but slightly weaker, pattern of findings emerged between RERT errors and performance on the EYES test (Happy:  $r = -.177, p = .053$ ; Sad:  $r = -.251, p = .006$ ; Angry:  $r = -.289, p = .001$ ; Disgust:  $r = -.217, p = .017$ ; Fear:  $r = -.382, p < .001$ ).

**Table 3-1 Descriptive statistics and correlations between autism symptoms, alexithymic traits, and task performance.**

	M	SD	1	2	3	4	5	6	7	8	9	10	11
1. AQ	15.50	5.18											
2. TAS	46.83	10.04	.437										
			<i>p</i> < .001										
3. MASC	34.74	4.45	-.404	-.402									
			<i>p</i> < .001	<i>p</i> < .001									
4. EYES	79.34	10.10	-.218	-.303	.288								
			<i>p</i> = .017	<i>p</i> = .001	<i>p</i> = .001								
5. SAM	.001	1.73	.023	-.106	-.036	.158							
			<i>p</i> = .804	<i>p</i> = .249	<i>p</i> = .692	<i>p</i> = .083							
6. RERT Fear	35.67	19.95	.171	.250	-.380	-.382	-.153						
			<i>p</i> = .061	<i>p</i> = .006	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> = .093						
7. RERT Angry	44.28	19.88	.210	.243	-.383	-.289	-.152	.524					
			<i>p</i> = .021	<i>p</i> = .007	<i>p</i> < .001	<i>p</i> = .001	<i>p</i> = .095	<i>p</i> < .001					
8. RERT Disgust	45.73	18.73	.136	.145	-.266	-.217	.016	.378	.319				
			<i>p</i> = .137	<i>p</i> = .112	<i>p</i> = .003	<i>p</i> = .017	<i>p</i> = .859	<i>p</i> < .001	<i>p</i> < .001				
9. RERT Sad	31.71	16.58	.224	.223	-.464	-.251	-.185	.410	.389	.123			
			<i>p</i> = .014	<i>p</i> = .014	<i>p</i> < .001	<i>p</i> = .006	<i>p</i> = .042	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> = .179			

**Table 3-1 continued.**

	M	SD	1	2	3	4	5	6	7	8	9	10	11
10. RERT Happy	5.68	10.65	.057	.134	-.306	-.177	-.052	.435	.433	.366	.468		
			<i>p</i> = .538	<i>p</i> = .142	<i>p</i> < .001	<i>p</i> = .053	<i>p</i> = .574	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> < .001		
11. Age	18.43	1.93	.168	-.382	.348	.187	.084	-.308	-.317	-.140	-.327	-.241	
			<i>p</i> = .065	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> = .040	<i>p</i> = .360	<i>p</i> = .001	<i>p</i> < .001	<i>p</i> = .125	<i>p</i> < .001	<i>p</i> = .008	
12. IQ	102.02	11.55	-.084	-.347	.380	.241	.145	-.417	-.334	-.204	-.469	-.358	.476
			<i>p</i> = .358	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> = .008	<i>p</i> = .112	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> = .025	<i>p</i> < .001	<i>p</i> < .001	<i>p</i> < .001

*Note.* MASC, Movie for the Assessment of Social Cognition; EYES, Reading the Mind from the Eyes Test; Self-Assessment Manikin task; RERT, Rapid Emotion Recognition Test.

Partial correlation coefficients were computed to investigate the association between ASD traits, alexithymia, and RERT performance. Preliminary analyses indicated that age and estimated IQ were significantly correlated with RERT performance. Therefore, two sets of analyses were conducted. First, age and estimated IQ were entered as control variables to adjust for the influence of cognitive ability and developmental stage. Second, in order to evaluate the unique variance of ASD symptomatology, we partialled out the variance of trait alexithymia. This analysis was intended to further assess hypotheses H1, H2, and H9.

As can be observed in Table 3.2, findings from the first set of analyses revealed a significant positive association between ASD traits and RERT errors on sad trials ( $r = .19$ ,  $p = .035$ ). In addition, the positive correlation between autism symptomatology and expressions of anger indicated a trend towards significance ( $r = .17$ ,  $p = .063$ ). However, the remaining associations between ASD traits and expressions of fear, disgust, and happiness failed to reach statistical significance. A Steiger's Z-test was conducted on the average partial correlation between ASD traits and percentage of errors on the RERT (controlling for WASI scores and age) for all negative emotional facial expressions (fear, anger, disgust and sadness) combined and the partial correlation between ASD traits and percentage of RERT errors for the positive emotional facial expression (happiness). This test was non-significant ( $Z=1.37$ ,  $p>.05$ ), suggesting that the partial correlations for the negative emotional facial expressions were not significantly stronger than that for the positive emotional facial expression.

Findings from the second set of analyses indicate that the association between elevated ASD traits and impaired sadness recognition remained significant once the variance for alexithymia was partialled out. Taken together, these findings indicate a unique association between autism symptomatology and impaired sadness recognition.

**Table 3-2 Partial correlation coefficients for autism symptomatology, alexithymia, and RERT**

<i>Criterion Variables</i>	<i>ASD traits</i>	
	<i>Control variables</i>	<i>IQ, Age</i>
<b>RERT Emotion</b>		
		<i>IQ, age, alexithymia</i>
	r	r
Fear	.13 <i>p</i> = .150	.10 <i>p</i> = .262
Angry	.17 <i>p</i> = .063	.14 <i>p</i> = .121
Disgust	.12 <i>p</i> = .210	.10 <i>p</i> = .305
Happy	.02 <i>p</i> = .862	.02 <i>p</i> = .805
Sad	.19* <i>p</i> = .035	.20* <i>p</i> = 0.34

*Note.* RERT, Rapid Emotion Recognition Test.

### 3.4.2. Multiple regression analyses

Next, forced-entry multiple regression analyses were conducted to investigate the association between ASD traits and ToM performance, whilst controlling for alexithymia, age, and general cognitive ability. This analysis was intended to further assess hypothesis H2 and H3. For the model predicting naturalistic ToM performance, total MASC scores were regressed onto ASD traits, alexithymia, age, and IQ. The regression model was significant ( $R = .56$ ,  $R^2$  adj = .29,  $F(4, 116) = 13.308$ ,  $p < .001$ ), with the four predictors collectively explaining 32% of the variance in MASC scores. ASD traits ( $\beta = -.30$ ,  $t(116) =$



3.52,  $p = .001$ ) and IQ ( $\beta = .25$ ,  $t(116) = 2.75$ ,  $p = .007$ ) both emerged as significant predictors of naturalistic ToM performance in the equation. The sign of the coefficients suggest that elevated levels of ASD traits and lower IQ scores were related to difficulties in mental state attribution. Neither alexithymia ( $\beta = -.14$ ,  $t(116) = 1.44$ ,  $p = .152$ ), nor age ( $\beta = .13$ ,  $t(116) = 1.42$ ,  $p = .159$ ) reached significance levels. Based on a probability level of 0.5, a total of four predictors, and an observed  $R^2$  of .32, a sample of 121 participants yielded a power of approximately 0.99 for the current analysis.

To examine hypothesis H3 and to further test H2, static ToM performance, accuracy scores on the EYES test were regressed onto the same set of predictor variables. The regression model was significant,  $R = .35$ ,  $R^2 \text{ adj} = .09$ ,  $F(4, 116) = 4.12$ ,  $p = .004$ , with the four predictors collectively explaining 12% of the variance in EYES scores. None of the predictors in the model reached individual statistical significance, ASD traits ( $\beta = -.12$ ,  $t(116) = 1.23$ ,  $p = .227$ ), IQ ( $\beta = .16$ ,  $t(116) = 1.53$ ,  $p = .129$ ), and age ( $\beta = .02$ ,  $t < 1$ ,  $p = .842$ ). However, alexithymia showed a trend towards significance ( $\beta = -.19$ ,  $t(116) = 1.80$ ,  $p = .075$ ). Gender was included in all analyses and subsequently removed after returning non-significant results. Based on a total of four predictors and an observed  $R^2$  of .16, a sample of 121 participants yielded a power of approximately 0.91 ( $\alpha = .05$ ) for the multiple regression model outlined above. With respect to correlational analyses, the current sample size yielded adequate statistical power (power = .95) to detect moderate effects (Cohen, 1988), using two-tailed tests with alpha set at .05.

### 3.4.3 *Summary of results*

These results suggest that individuals with elevated levels of autism traits experience a similar pattern of difficulties in sadness recognition and empathic processing to those with a clinical diagnosis of ASD. As predicted, findings showed that whilst mental state attribution is significantly impaired in those with higher levels of ASD traits, the ability to resonate with others' emotions remains largely intact. Furthermore, findings from multiple regression analyses suggest that individuals with higher ASD traits and lower IQ scores experience greater difficulties in identifying mental states from dynamic video-based

stimuli, but not from static images depicting the eye region of the face. However, despite significant associations with autism symptomatology, facial affect recognition, and measures of ToM, trait alexithymia did not explain the mentalising and emotion recognition difficulties associated with elevated levels of ASD traits, and was not related to performance on the affective empathy task. Taken together, these findings are consistent with the study predictions and yield partial support for H1, and full support for H2 and H3. Results from the first study further indicate partial support for hypotheses H7 and H8.

### **3.5 Method: Study 2**

#### *3.5.1. Participants*

One hundred and seven participants (16% male) from the original sample returned to complete part two of the study. Participants were aged 16-22 ( $M = 18.12$ ,  $SD = 1.24$ ), with IQs between 72 and 129 ( $M = 101.72$ ,  $SD = 11.51$ ). There were no statistically significant differences in IQ scores ( $t(119) = .781$ ,  $p = .437$ ) between returning participants and those completing the first half only ( $M = 104.29$ ,  $SD = 12.04$ ).

#### *3.5.2. Measures*

##### *3.5.2.1. Assessment of Executive Function*

*Cognitive Flexibility.* A computerised set-shifting task (Smillie et al., 2009) based on the Wisconsin Card Sorting Test (WCST; Grant & Berg, 1948), was used to assess cognitive flexibility. Each trial consisted of the presentation of a single card, which varied in three different ways: (1) was blue or yellow in colour, (2) displayed either a '0' or an 'X' on the front, and (3) appeared on the left or right side of the screen. Participants were instructed to sort the cards into two piles by pressing either the '\ ' or '/ ' key (which were marked as 'A' and 'B'). After each trial, participants were provided with feedback on the accuracy of their response.

Participants were informed that to learn how to sort the cards correctly, they would need to use the feedback and learn by trial-and-error. An unannounced shift in the sorting rule occurred after the participant had made 10 consecutive correct responses. In total, five shifts took place during the experiment with each of the rules repeating twice. The task

duration was approximately 10 minutes and finished once they had successfully achieved all five shifts or once they completed the maximum number of trials (120), whichever was earlier. Once again, performance was assessed in terms of the total number of shifts made and the shifting efficiency measure proposed by Cianchetti et al., (2005).

*Response Inhibition.* The Go/No-Go (Form S3; Kaiser et al, 2010) is a widely used measure of response inhibition. In this task, participants were required to respond as quickly and accurately as possible to all individually presented triangles (“go” trials), but to avoid responding to the circles (“no-go” trials). The stimuli were presented for 200 ms and the interstimulus intervals were 1000 ms. The Go/No-Go comprised two blocks and a total of 250 trials, 19% of which were “no-go” trials and the remaining 81% “go” trials. The main outcome variable recorded for this task was the number of trials in which the participant responded to a circle (Error of commission).

*Planning ability.* A computerized version of the Tower of London task (Freiburg Version, ToL-F; Kaller et al, 2012) task was used to assess planning ability. In this task, a set of differently coloured balls placed on three vertical rods of different heights are displayed on the screen. Participants are presented with a start state and instructed to re-configure the balls to match a given goal state while following three key rules: 1) Only one ball can be moved at a time, 2) balls cannot be placed outside the rods, and 3) if more than one ball is stacked on a rod, only the top ball can be moved. Participants were also instructed to solve each problem in the minimum number of moves set for each trial and to plan a solution before executing the sequence of movements. Experimental trials were presented in order of ascending difficulty and comprised a total of 24 problems (eight four-move problems, eight five-move problems, and eight six-move problems). The primary outcome measure for this task was number of problems correctly solved within a time limit of one minute per trial (Planning ability).

### 3.5.3. Procedure

Participants were administered a series of executive function tasks in a quiet, dimly lit room. Task order was randomised across each session and participants were provided

with instructions at the start of each test. The task-set took approximately 1.5 hours to complete and participants were allowed to take short breaks between the tasks as needed. Once again, these data were collected as part of a wider battery of measures

## 3.6 Results and Discussion

### 3.6.1 Preliminary Analysis

The study variables were visually inspected for normal distribution via QQ plots. Minor deviations from normality were detected for the WCST measure. All remaining variables demonstrated approximate normality. Given the relatively large sample size ( $n = 107$ ) in the present study, minor departures from normality are unlikely to cause a major issue (central limit theorem; Field, 2002).

### 3.6.2 Correlational Analyses

The means, standard deviations, and bivariate correlation coefficients for all variables are presented in Table 3.3. With the exception of WCST and ToL performance ( $r = .295, p = .002$ ), none of the executive function measures were interrelated (WCST-Go/No-Go:  $r = -.057, p = .599$ ; ToL-Go/No-Go:  $r = .112, p = .251$ ). As predicted, WCST scores showed a positive correlation with MASC ( $r = .386, p < .001$ ) and EYES ( $r = .336, p < .001$ ) performance. With the exception of sad expressions, analysis revealed a significant negative correlation between WCST performance and RERT errors (Happy:  $r = -.232, p = .016$ ; Sad:  $r = -.180, p = .063$ ; Angry:  $r = -.285, p = .003$ ; Disgust:  $r = -.256, p = .008$ ; Fear:  $r = -.359, p < .001$ ). ToL scores demonstrated a similar pattern with both ToM tasks (MASC:  $r = .247, p = .010$ ; EYES:  $r = .194, p = .045$ ), and established significant negative correlations across all basic emotions on the RERT (Happy:  $r = -.322, p = .001$ ; Sad:  $r = -.207, p = .033$ ; Angry:  $r = -.385, p < .001$ ; Disgust:  $r = -.251, p = .009$ ; Fear:  $r = -.424, p < .001$ ). However, whilst commission errors on the Go/No-Go revealed a negative correlation with MASC performance ( $r = -.207, p = .032$ ), there was no significant association with EYES performance ( $r = .016, p = .872$ ). Commission errors on the Go/No-Go tasks were negatively related to disgust ( $r = .204, p = .035$ ) and sadness ( $r = .204, p = .035$ ) and sadness ( $r = .204, p = .035$ ) and sadness ( $r = .204, p = .035$ )

= .193,  $p = .047$ ) recognition. Errors on all remaining RERT expressions were non-significant (Happy:  $r = .051$ ,  $p = .599$ ; Angry:  $r = -.107$ ,  $p = .272$ ; Fear:  $r = .082$ ,  $p = .401$ ). Finally, none of the executive function measures revealed a significant association with SAM performance (WCST:  $r = .054$ ,  $p = .578$ ; ToL:  $r = -.034$ ,  $p = .730$ ; Go/No-Go:  $r = -.060$ ,  $p = .524$ ).

**Table 3-3 Descriptive statistics and correlations between measures of facial affect processing, empathy, and executive functioning**

	M	SD	1	2	3	4	5	6	7	8	9	10	11	12
1. MASC	34.92	4.35												
2. EYES	79.58	10.19	.284											
3. SAM	.006	1.74	<i>p</i> = .003 -.090	.123										
4. RERT Fear	34.81	19.48	<i>p</i> = .359 -.349	<i>p</i> = .206 -.367	-.085									
5. RERT Angry	44.00	19.56	<i>p</i> < .001 -.340	<i>p</i> < .001 -.270	<i>p</i> = .384 -.139	.495								
6. RERT Disgust	45.48	18.54	<i>p</i> < .001 -.305	<i>p</i> = .005 -.188	<i>p</i> = .154 .026	<i>p</i> < .001 .385	.294							
7. RERT Happy	5.69	10.90	<i>p</i> = .004 -.278	<i>p</i> = .128 -.148	<i>p</i> = .752 -.031	<i>p</i> < .001 .440	<i>p</i> < .001 .407	<i>p</i> < .001 .369						
8. RERT Sad	30.92	16.02	<i>p</i> < .001 -.432	<i>p</i> = .010 -.249	<i>p</i> = .095 -.162	<i>p</i> < .001 .380	<i>p</i> < .001 .371	<i>p</i> = .075 .173	<i>p</i> < .001 .455					
9. WCST	25.02	16.00	<i>p</i> < .001 .386	<i>p</i> < .001 .336	<i>p</i> = .578 .054	<i>p</i> < .001 -.359	<i>p</i> = .003 -.285	<i>p</i> = .008 -.256	<i>p</i> = .016 -.232	<i>p</i> = .063 -.180				
10. GNG	13.41	6.31	<i>p</i> = .032 -.207	<i>p</i> = .872 .016	<i>p</i> = .542 -.060	<i>p</i> = .401 .082	<i>p</i> = .272 .107	<i>p</i> = .035 .204	<i>p</i> = .599 .051	<i>p</i> = .047 .193	<i>p</i> = .272 -.057			
11. ToL	14.87	3.62	<i>p</i> = .010 .247	<i>p</i> = .045 .194	<i>p</i> = .730 -.034	<i>p</i> < .001 -.424	<i>p</i> < .001 -.358	<i>p</i> = .009 -.251	<i>p</i> = .001 -.322	<i>p</i> = .033 -.207	<i>p</i> = .002 .295	<i>p</i> = .251 .112		
12. Age	18.21	1.24	<i>p</i> < .001 .407	<i>p</i> = .077 .172	<i>p</i> = .989 -.001	<i>p</i> = .001 -.323	<i>p</i> = .003 -.289	<i>p</i> = .103 -.159	<i>p</i> = .018 -.229	<i>p</i> < .001 -.369	<i>p</i> = .030 .210	<i>p</i> = .249 -.122	<i>p</i> < .001 .387	
13. IQ	101.72	11.51	<i>p</i> < .001 .378	<i>p</i> = .041 .198	<i>p</i> = .326 .096	<i>p</i> < .001 -.374	<i>p</i> = .002 -.289	<i>p</i> = .069 -.176	<i>p</i> = .001 -.324	<i>p</i> < .001 -.486	<i>p</i> = .001 .304	<i>p</i> = .609 .050	<i>p</i> < .001 .419	<i>p</i> < .001 .528

*Note.* MASC, Movie for the Assessment of Social Cognition; EYES, Reading the Mind from the Eyes Test; Self-Assessment Manikin task; RERT, Rapid Emotion Recognition Test; WCST, Wisconsin Card-Sort Test; GNG, Go/No-Go; ToL, Tower of London task.

### 3.6.3 Multiple regression analyses

Next, forced-entry multiple regression analyses were conducted to investigate the association between ToM performance, executive functioning, and subclinical ASD traits whilst controlling for age and general cognitive ability. Total MASC scores were regressed onto WCST, GNG, ToL, ASD traits, age, and IQ. The regression model was significant,  $R = .60$ ,  $R^2 \text{ adj} = .32$ ,  $F(6, 100) = 9.30$ ,  $p < .001$ , and together, the six predictors explained 36% of the variance in MASC scores. ASD traits ( $\beta = -.24$ ,  $t(100) = 2.86$ ,  $p = .005$ ) and WCST performance ( $\beta = .24$ ,  $t(100) = 2.78$ ,  $p = .007$ ) emerged as significant predictors of naturalistic ToM performance in the equation. The signs of the coefficients suggest that higher ASD traits and lower levels of cognitive flexibility are related to difficulties in mental state attribution in a naturalistic context. None of the other predictors in the model reached statistical significance, GNG ( $\beta = -.13$ ,  $t(100) = 1.51$ ,  $p = .135$ ), and ToL ( $\beta = .04$ ,  $t < 1$ ,  $p = .656$ ). However, IQ ( $\beta = .19$ ,  $t(100) = 1.87$ ,  $p = .065$ ) and age ( $\beta = .17$ ,  $t(100) = 1.73$ ,  $p = .086$ ), indicated a trend towards significance. Based on a probability level of 0.5, a total of six predictors, and an observed  $R^2$  of .36, a sample of 107 participants yielded a power of approximately 0.99 for the current analysis.

For the model predicting static ToM performance, accuracy scores on the EYES test were regressed onto the same set of predictors. Once again, the regression model was significant,  $R = .40$ ,  $R^2 \text{ adj} = .11$ ,  $F(6, 100) = 3.17$ ,  $p = .007$ , and together, the six predictors explained 16% of the variance in EYES scores. WCST performance ( $\beta = .27$ ,  $t(100) = 2.75$ ,  $p = .007$ ), emerged as a significant predictor of static ToM. In addition, ASD traits ( $\beta = -.18$ ,  $t(100) = 1.85$ ,  $p = .067$ ) revealed a trend towards statistical significance. However, none of the remaining predictors in the equation reached statistical significance, GNG ( $\beta = .07$ ,  $t < 1$ ,  $p = .481$ ), ToL ( $\beta = .07$ ,  $t < 1$ ,  $p = .511$ ), IQ ( $\beta = .06$ ,  $t < 1$ ,  $p = .616$ ), and age ( $\beta = .02$ ,  $t < 1$ ,  $p = .831$ ). Based on a 0.5 criterion of statistical significance, a total of six predictors, and an observed  $R^2$  of .16, a sample of 107 participants yielded a power of approximately 0.93 for the current analysis.

Last, bivariate correlations were computed to assess the relationship between ASD traits, alexithymia, and executive function (see Table 3.4). There was a significant positive

correlation between ASD traits and commission errors on the GNG task ( $r = .250, p = .009$ ). Analysis also revealed a significant negative association between ASD symptomatology and WCST Shift scores ( $r = -.224, p = .021$ ). However, the negative correlation between ASD traits and WCST Efficiency scores and ToL performance was not statistically significant ( $p > .05$ ). A similar pattern emerged with trait alexithymia. Whilst there was a significant positive association with GNG scores ( $r = .219, p = .023$ ), the negative relationship with WCST (WCST Efficiency:  $r = -.135, p = .165$ ; WCST Shift:  $r = -.134, p = .165$ ) and ToL did not reach statistical significance ( $r = -.153, p = .116$ ), respectively. Once again, gender was included in all analyses and subsequently eliminated after returning non-significant results. In terms of correlational analyses, the current sample size yielded adequate statistical power (power = .95) to detect moderate effects (Cohen, 1988), using two-tailed tests with alpha set at .05.

#### 3.6.4 Summary of results

Taken together, findings from the second study indicate a substantial overlap between facial affect recognition, empathic processing, executive function, and ASD traits. Findings demonstrate that accuracy in detecting basic expressions of emotion were associated with better performance on multiple aspects of executive control. These associations were particularly pronounced for the accurate recognition of fear. Similarly, analysis revealed that higher scores on the naturalistic ToM task were associated with better performance across all components of executive processing. With the exception of response inhibition, static ToM performance revealed a similar pattern of associations with executive control. By contrast, no statistically significant associations between the affective domain of empathy and executive function were found.

These findings also demonstrate age-related improvements on affect processing and naturalistic ToM, as well as on the set-shifting and planning domains of executive control. However, the association between age, affective empathy, and commission errors on the response inhibition task did not reach statistical significance.

The multiple regression analyses suggested that the accurate decoding of mental states from video-based stimuli is associated with lower levels of autism symptomatology



and flexible cognition, whilst of the executive function measures used in this study, accurate performance on the static EYES test is exclusively associated with set-shifting ability.

As regards to the relationship between autism symptomatology and executive function, findings showed that individuals with higher levels of ASD traits experience a similar pattern of impairments in set-shifting and response inhibition as those observed in ASD. Lastly, trait alexithymia was also associated with impaired response inhibition, but planning and set-shifting abilities were found to be intact. Together, these data yield strong support for H4 and H5, provide partial support for H6 and H9, and indicate age-related advancements in facial affect recognition, mentalising ability, and executive control.

**Table 3-4 Descriptive statistics and correlations between measures of autism symptomatology, alexithymic traits, and executive function.**

	1	2	3	4	5
1. AQ					
2. TAS	.476**				
	$p < .001$				
3. WCST Shift	-.224	-.134			
	$p = .021$	$p = .165$			
4. WCST Efficiency	-.133	-.135	.829		
	$p = .171$	$p = .165$	$p < .001$		
5. GNG	.250	.219	-.152	-.057	
	$p = .009$	$p = .023$	$p = .117$	$p = .559$	
6. ToL	-.013	-.153	.231	.295	.112
	$p = .892$	$p = .116$	$p = .016$	$p = .002$	$p = .165$

*Note.* AQ, Autism Spectrum Quotient; TAS, Toronto Alexithymia Scale; Wisconsin Card-Sort Test, WCST; Go/No-Go, GNG; Tower of London task, ToL.

### 3.7. General Discussion

Recent investigations suggest that social cognition and executive function are interrelated constructs following a protracted course of development, and that autism-related difficulties in social and executive processing go beyond individuals diagnosed with ASD. In contrast to increasing interest in the link between executive control and social cognition, and in their respective relationships with autism, little relevant research has been conducted at the subclinical level.

The current study addressed this gap in the literature by examining the link between facial affect processing, empathic functioning, executive control, and autism symptomatology in a sample of typically developing adults and adolescents. This is the first study of its kind to provide a comprehensive investigation of this relationship in a non-clinical population. The obtained results replicate and extend previous work by documenting six key findings: (i) impaired sadness recognition is associated with higher levels of autism symptomatology; (ii) naturalistic ToM is associated with elevated levels of autism traits, as well as general cognitive ability; (iii) along with ASD traits, decoding mental states from dynamic stimuli is related to executive control; (iv) accurate detection of basic emotions is significantly associated with superior executive control; (v) individuals with high autism traits experience a similar pattern of executive problems as those observed in ASD; and (vi) impaired sadness recognition and mentalising ability in those with elevated levels of ASD traits are not explained by co-occurring alexithymia.

#### 3.7.1. *Associations between Social Cognition, Autism Symptomatology, and Alexithymia*

As expected, data from the first part of this study revealed a negative correlation between ASD traits and measures of static and naturalistic ToM. Similarly, trait alexithymia was also negatively correlated with performance on both ToM tasks. ASD traits and alexithymia demonstrated positive associations between RERT errors on trials presenting expressions of sadness and anger. By contrast, neither ASD traits nor alexithymia were related to performance on the affective empathy task. Whilst findings in relation to impaired cognitive and spared affective empathy in ASD traits converge with existing autism literature (Dziobek et al., 2008; Jones et al., 2010; Lockwood et al., 2013; Schwenk et al., 2012), the lack of association between alexithymia and reduced affective empathy is somewhat surprising and inconsistent with previous reports (Bird et al., 2010;

Lockwood et al., 2013). Nonetheless, the negative association between alexithymia and ToM performance yields support for previous work reporting alexithymia-related deficits in the cognitive domain of empathy (Moriguchi et al., 2006).

In terms of facial affect recognition, the analysis revealed significant associations with mentalising ability. For instance, higher scores on the naturalistic MASC task were negatively related to RERT errors across all basic emotions. A similar pattern emerged for the static EYES test, although the negative association between happy errors failed to reach statistical significance. These associations indicate an important overlap between accurate emotion recognition abilities and mental state reasoning. The finding of a modest positive association between ASD traits and alexithymia replicates data reported in previous studies (Lockwood et al., 2013). In addition, the non-significant correlations between measures tapping cognitive and affective empathy suggest that these tasks capture distinct components of empathic processing.

Further analysis demonstrated unique associations between ASD traits and impaired mentalising ability on a naturalistic measure of ToM. Alexithymia and age did not make a significant contribution to task performance in this model; however, IQ emerged as an independent contributor to mentalising ability on the MASC. In contrast, analysis did not reveal any unique associations between ASD traits and performance on a static measure of ToM. Taken together, these results suggest that individuals with higher levels of ASD traits and lower IQ experience significant difficulties in attributing mental states to movie characters in a real-life social context, but not to static images depicting the eye region of the face. This finding is of particular importance, as it shows that along with capturing more profound ToM deficits present in clinical populations (Dziobek et al., 2006; Lahera et al., 2014), the MASC is also sensitive in detecting subtle mindreading impairments in typically developing adults and adolescents.

Indeed, the fact that IQ made an independent contribution to MASC performance suggests that, along with autism symptomatology, general cognitive ability also plays a role in mental-state reasoning in typical development. This finding speaks against previous reports documenting non-significant associations between MASC performance and IQ scores (Dziobek et al., 2006; Lahera et al., 2014), and, instead, converges with studies documenting a positive link between ecologically valid assessments of ToM and intellectual capacity (Heavey et al., 2000; Ponnet et al., 2008). Consequently, our data indicate the involvement of multiple processes in successful mentalization, and highlight

the value of incorporating non-social cognitive domains in the study of empathic processing.

With regards to facial affect recognition, analysis revealed greater RERT errors on trials depicting facial expressions of sadness. Of note, this association remained significant after adjusting for the influence of age, general, cognitive ability and trait alexithymia. Taken together, these data indicate support for previous work documenting atypical sadness recognition in ASD (Ashwin et al., 2006; Ellis & Leafhead, 1996) and extend these findings to a sample of typically developing adults and adolescents. This specific impairment may also indicate a pattern of ASD-related impairments unique to subclinical populations. As previously discussed, studies examining affect recognition have yielded inconsistent results, with some reporting impairments across a range of basic negative emotions (e.g., Ashwin et al., 2006; Ellis & Leafhead, 1996; Golan & Baron-Cohen, 2006; Howard et al., 2000), and others indicating typical performance (Adolphs et al., 2001; Castelli, 2005; Tracy et al., 2011). The fact that higher ASD traits were associated with poorer sadness recognition over more perceptually distinct emotions, such as fear and anger, points to a qualitatively similar, though less severe, pattern of impairments in those with higher levels of ASD traits. In other words, whilst individuals with higher autism symptomatology experience difficulties in processing expressions of sadness, their ability to identify other, more distinct negative emotions appears to be intact. These findings further contradict recent reports suggesting that comorbid alexithymia may account for the emotional difficulties characteristic of ASD (Cook et al., 2013).

In sum, results from the first study support previous research documenting mentalising deficits in typically developing individuals with higher levels of autism traits (Gökçen et al., 2014; Lockwood et al., 2013), and extend these findings to include a naturalistic measure of ToM. Interestingly, findings concerning alexithymia appear to be inconsistent with recent theory and evidence suggesting that alexithymic traits account for the observed empathy and affect processing deficits related to ASD (Bird & Cook, 2013; Cook et al., 2013). These data are in line with Lockwood et al., (2013), and show that alexithymia does not explain the mindreading difficulties associated with elevated ASD traits, nor the deficits in sadness recognition.

### *3.7.2. Associations between Executive Function, Social Cognition, Autism Symptomatology, and Alexithymia*

Findings from the second study revealed significant associations between facial affect recognition, ToM performance, and executive control. As expected, MASC scores were positively correlated with set-shifting and planning ability, and negatively associated with commission errors on the GNG tasks. A similar pattern emerged with EYES performance, such that scores on this task were positively related to measures of cognitive flexibility and planning performance. However, no significant association was found between the EYES and the GNG tasks. Furthermore, none of the sub-domains of executive function were related to the measure assessing affective empathy. RERT errors across all emotions were negatively associated with WCST and ToL performance. Similarly, impaired sadness and anger recognition were related to more commission errors on the Go/No-Go paradigm. Taken together, these findings indicate important overlap between facial affect processing and executive control. With the exception of disgust, age was negatively associated with errors in identifying basic emotions, and positively related to both static and naturalistic ToM performance, as well as to the set-shifting and planning domains of executive function. However, the negative correlation between age and GNG performance failed to reach statistical significance. Similarly, IQ was positively associated with naturalistic and static ToM performance, and negatively associated with errors in identifying facial expressions of basic emotions. Furthermore, higher IQ scores were related to better performance on measures of working memory, planning, and cognitive flexibility, but not with response inhibition. Interestingly, these data also suggest that although certain measures of executive control share some variance, they capture different aspects of higher order processing.

Additional analyses revealed unique associations between MASC performance and executive function. For instance, along with ASD traits, cognitive flexibility emerged as a significant predictor of MASC score. With respect to the EYES test, cognitive flexibility was the only predictor to reach statistical significance. Collectively, these data are consistent with the view that autism symptomatology and flexible cognition are vital factors for optimal performance on a naturalistic measure of ToM. However, of the social and executive function variables included in the present study, decoding mental states from static images appears to call solely upon the executive domain of cognitive flexibility.

The influential role of autism symptomatology and executive processing is perhaps not surprising given that the MASC provides a closer approximation of the intricacies involved in everyday social interactions. For example, by presenting dynamic interactions in a real-world context, the MASC empirically evaluates participant capacity to recognise characters' thoughts, emotions, and intentions from multiple channels of communication in a real-life context. Since this task provides a more complex and ecologically valid assessment of mentalising ability, successful performance on it is likely to be sub-served by a number of factors enabling flexible adaptation to changing social contexts, and the capacity to shift between our own and others' perspectives during mental state reasoning. In contrast to video-based assessments of ToM, mental-state attribution to static images is likely to make less of a demand upon available processing resources.

These data are inconsistent with previous work reporting non-significant associations between MASC performance and executive control. One explanation for this apparent discrepancy may lie in the type of executive function tasks employed. For instance, Lehara and colleagues (2014) assessed the MASC and executive control relationship using only a brief measure of neurocognition (i.e., Screen for Cognitive Impairment in Psychiatry; Purdon, 2005), rather than a comprehensive battery of tasks. In addition, Dziobek et al. (2006) administered a different set of tasks that may not have tapped variation in executive control as well as the battery of measures employed in the present investigation. Therefore, replication of these methodologies and findings in ASD populations may help resolve the inconsistencies surrounding the association between MASC and executive control.

Interestingly, the positive association between age and executive function, in combination with the finding that younger participants make more ToM errors, appears to be in line with the notion that social cognition and executive function follow a protracted developmental course (Decety, 2010; Dumontheil et al., 2010). Findings also suggest a significant association between autism symptomatology and difficulties in executive processing. For instance, analysis showed that individuals with higher ASD traits were less accurate on the GNG task and achieved fewer set-shifts on the WCST. However, it should be noted that the negative association between autism traits and shifting efficiency- a more sensitive index of flexible cognition- failed to reach statistical significance. In addition, no significant association was found between planning ability and ASD traits. With respect to alexithymia, impairments were only observed on the response inhibition domain of executive processing.

The observed relationships between autism symptomatology, cognitive flexibility, and impaired response inhibition are in line with previous reports from ASD populations (Pellicano, 2007; Robinson et al, 2009; though see Hill, 2004a, 200b), but partly contradict data from Christ et al's (2010) study examining executive functioning in subclinical ASD traits. Again, the conflicting pattern of results should be viewed in light of the assessment techniques employed. For example, whilst Christ et al (2010) used a self-report measure of higher-order processing, the present study administered a behavioral index of all relevant executive domains. Therefore, it is possible that the behavioural methodology employed by the current study is better able to detect individual differences in response inhibition. Together, these findings demonstrate that response inhibition and cognitive flexibility are adversely affected in those with higher levels of ASD traits, and suggest that the executive processing difficulties characterising ASDs extend beyond people with a clinical diagnosis, into the general population. However, given that people with clinical ASD typically exhibit deficits planning and cognitive flexibility, whilst response inhibition remains largely intact (Hill, 2004a, 2004b), these data yield only partial support for the hypothesis that individuals with high levels of subclinical autism traits have a similar profile of executive deficits as their peers with clinical ASD.

In addition to informing our understanding of the broader autism phenotype, these results also have implications for clinical practice. Importantly, they indicate that cognitive empathy and executive function are key processes to consider when designing intervention programmes targeting adaptive social functioning in typically developing populations with elevated levels of autism traits. With regards to clinical ASD, the finding that naturalistic ToM was related to deficits in cognitive flexibility suggests that this executive domain may be particularly relevant for enhancing the treatment effects of social interventions. In other words, a multi-tier approach to social interventions may be necessary to improve socio-adaptive outcomes and alleviate the direct and indirect negative consequences associated with interpersonal difficulties in ASD. A further implication of these findings concerns the selection of control participants in autism research. Controlling for ASD traits in typically developing populations may be particularly important when examining ToM and executive function abilities, as variability in these traits may influence task performance and hinder the accurate profiling of social and non-social processes in clinical ASD. The presence of significant group differences in social and executive processing abilities might, therefore, depend on whether control



participants are nearer the higher or lower end of the broader autism spectrum range (von dem Hagen et al, 2011). Thus, establishing levels of subclinical autism symptomatology could provide a more accurate profile of the neurocognitive processes underpinning social dysfunction in ASD.

### *3.7.3. Limitations and directions for future research*

Most participants in this study were female, leading to a significant gender imbalance in our sample. This is a consequence of primarily recruiting Psychology students (undergraduate and A-level), where there is an evident female bias. Although analysis revealed no confounding by gender, the association between executive control and mentalizing difficulties may vary across males and females with elevated autism traits. For instance, recent investigations have reported gender-specific cognitive impairments in ASD, with high-functioning autistic males evidencing greater deficits in sub-domains of executive control relative to their female counterparts (Bölte Duketis, Poustka, & Holtmann, 2011; Lehnhardt et al, 2016). Thus, given that executive function impairments in ASD are partially modulated by sex, and that better executive control potentiates socio-communicative skills (Bölte et al, 2011), examining these processes in more balanced, or male-dominated samples could reveal a stronger association between executive control and ToM deficits. To address this gap in the literature, future investigations should compare male and female participants in order to help determine whether sex-related differences in neurocognitive processing extend to subclinical ASD. A further aim would be to ascertain the extent to which these differences influence the link between impaired ToM and executive dysfunction. As it stands, the pattern of results observed in the current study may be female-specific and limited in its generalizability to male samples. Second, the study does not address the issue of directionality between ToM and executive control deficits. The extent to which impairments in mentalizing ability may be accounted for by executive dysfunction is, therefore, unclear and warrants further investigation. Third, whilst naturalistic assessments provide a closer approximation of empathic processing, in real-life social situations, mental-state reasoning and empathic responses occur in the context of reciprocal social interactions. Consequently, it would be of particular interest to observe participants' interpersonal competence in an experimental setting. Such a line of investigation would also help determine whether the processing deficits associated with elevated autism symptomatology can explain real-world social functioning. Finally, future investigations should also utilise dual-task paradigms to assess

social and non-social information processing simultaneously. Whilst these data corroborate the notion that executive function and ToM are closely bound constructs, examining them in tandem could be instrumental to our understanding of successful social performance in everyday contexts and, ultimately, to the design of interventions programmes targeting interpersonal performance. More immediately, the potential importance for clinicians is highlighted of assessing both cognitive empathy and executive function in individualising programmes in order to support the social functioning of adolescents and young adults, even when there is no ASD diagnosis. Finally, whilst the current study yielded sufficient statistical power to detect moderate effects, future investigations may benefit from increasing the sample size in order to increase sensitivity to smaller effects.

### **3.8. Conclusions**

In summary, findings from the current study suggest that ASD traits, executive function, age, and general cognitive ability are important factors contributing to optimal mentalising ability. Moreover, findings also show that individuals with elevated levels of autism traits display a similar profile of difficulties in affect recognition and empathic processing, and a partially comparable pattern of executive control deficits to those observed in ASDs. Further investigation of these processes in both clinical and sub-clinical ASD has the potential to advance our understanding of the broader autism phenotype as well as to elucidate the neurocognitive underpinnings of adaptive social behaviour.

## **4 Dual assessment of social cognition and executive control in subclinical autism symptomatology**

## 4.1 Chapter Introduction

Chapter 3 presented a two-part study examining associations between facial affect recognition, empathic processing (affective empathy, static, and naturalistic mentalising), executive function (planning ability, cognitive flexibility, and response inhibition), and autism symptomatology in a sample of typically developing adults and adolescents. Findings showed that: (i) impaired sadness recognition is associated with elevated autism symptomatology; (ii) naturalistic ToM is associated with higher levels of ASD traits and general cognitive ability; (iii) along with ASD traits, decoding mental states from dynamic stimuli is related to executive control; (iv) accurate detection of basic emotions is significantly associated with superior executive control; (v) individuals with high autism traits experience a similar pattern of executive problems to those observed in ASD; and (vi) impaired sadness recognition and mentalising ability in those with elevated levels of ASD traits are not explained by co-occurring alexithymia. These results support the notion that executive function, facial affect recognition, and mentalising ability are related processes following a protracted developmental trajectory, and suggest that individuals with elevated levels of autism-like traits experience a similar pattern of social and executive function difficulties to those diagnosed with ASD. However, given that studies have primarily focused on assessing social and non-social domains separately, the potential interaction between social and executive functioning remains relatively underexplored. As a result, very understanding of whether subclinical levels of ASD traits are associated with variability in processing social information in the context of executive control remains considerably limited. To bridge this gap in the literature, the present study employed a set of tasks concurrently assessing social and executive functioning. Namely, a dual-task paradigm was employed to examine the interaction between ToM use and executive functioning under varying levels of cognitive load. This study also utilised a test of rapid emotion discrimination in the context of a standard go/no-go task in order to examine how affective information impacts executive processing.

### 4.1.1. *Dual Assessment of Social Cognition and Executive Control*

As discussed in previous chapters, successfully navigating our social environment requires us to rapidly and accurately process a continuous stream of socio-affective signals, merge this input with pre-existing knowledge about our own and others beliefs and expectations, and to use this information to guide our behaviour in an adaptive and

goal-directed manner (Thornton & Conway, 2013). In order to perform these tasks in a seamless fashion, we need to maintain focus, problem-solve, flexibly shift between self and other perspectives, regularly update our representation of others', and inhibit inappropriate actions (Thornton & Conway, 2013; Ybarra & Winkielman, 2012). In addition to decoding socially-relevant cues, many real-world interactions also entail the concurrent processing of non-social information (Mills & Blakemore, 2014; Mills, Dumontheil, Speekenbrink, & Blakemore, 2015). Thus, communicating in a context where we have to keep track of multiple strings of data is likely to place increased demands on our cognitive resources and impede social performance. Nevertheless, how communicative behaviour is affected in such situations is not yet clear (Mills & Blakemore, 2014).

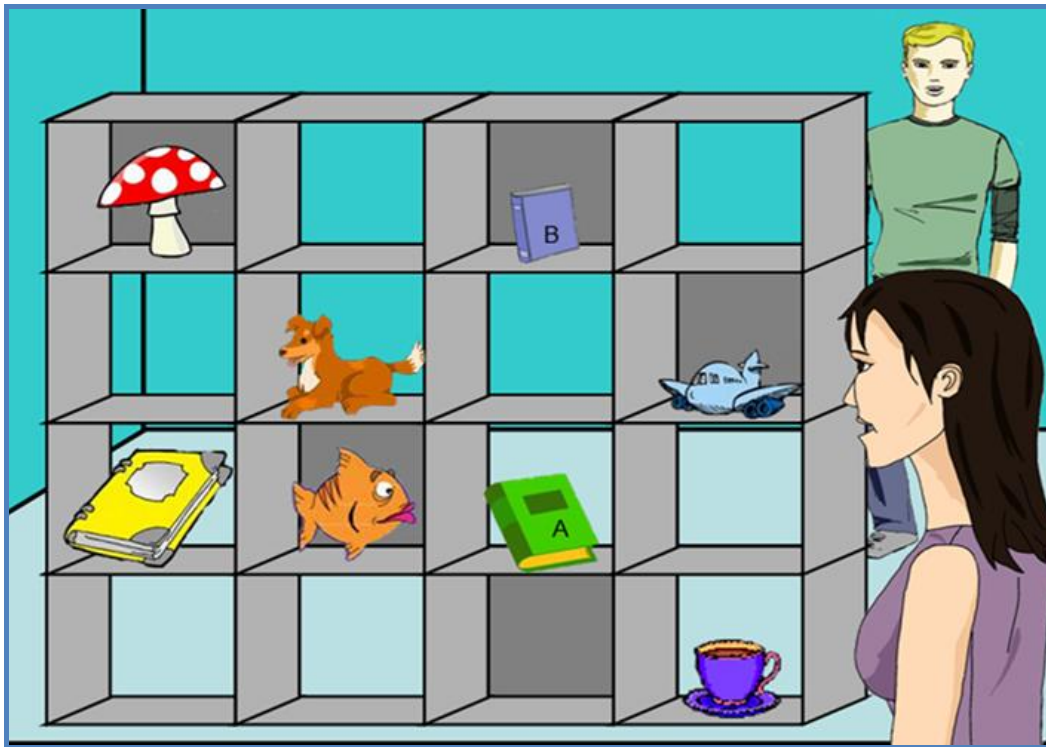
The complex and demanding nature of social behaviour suggests that other higher-order cognitive abilities, such as executive control, may play a critical role in social cognition. One possibility is that increases in socio-affective processing demands are supported by a suite of generic executive domains, such as working memory, cognitive flexibility, and response inhibition. These processes allow one to monitor and flexibly adjust ongoing behaviour in line with varying situational demands (Corbett, et al., 2009; Gyurak, et al., 2009; Lezak, 1995; Lezak, et al., 2004), and frequently interact with social and affective content (Schel & Crone, 2013; Tottenham et al., 2011). In fact, in everyday life, these cognitive mechanisms rarely stand-alone, and we often deploy executive control in the context of complex and multifaceted social interactions (Schel & Crone, 2013; Ybarra & Winkielman, 2012).

The association between executive functioning and interpersonal skills has long been emphasised in social cognition literature. For instance, studies examining this link in typically developing populations have consistently revealed a positive relationship between executive processing and ToM performance (Apperly et al., 2009; Austin et al., 2014; Bull et al., 2008; Carlson et al., 2013; Carlton et al., 2002; Gökçen et al., 2014; Hughes, 1998a; Perner & Lang, 2000; Sabbagh, et al., 2006; Vetter et al., 2013; Chapters 2 & 3; though see also Pellicano et al., 2007). A similar association has also emerged between executive abilities and facial affect processing, with findings showing greater emotion recognition skills for those with better executive control (David, Soeiro-de-Souza, Moreno, & Bio, 2014; Chapters 2 & 3).

However, whilst these reports indicate a meaningful relationship between social cognition and executive functioning, most studies have examined these processes

separately and provide limited insight into how they might interact. For instance, measures of social cognition have generally involved the passive viewing of social stimuli (e.g., EYES test, MASC task, and measures of basic emotion recognition), and require minimal input from participants. With respect to executive function, studies have almost exclusively focused on cognitive or perceptual information (i.e., letters, numbers, and shapes), rather than assessing social and executive processing in a single paradigm. Thus, although a number of studies report a significant overlap between social and executive abilities, very little is known about how processing socio-affective information in the context of executive control influences task performance.

In an attempt to resolve this particular issue, a number of recent investigations have developed ecologically valid paradigms combining social and executive processing. One notable example is the Director Task (Apperly et al., 2010; Dumontheil et al., 2010; Dumontheil et al., 2012; Keysar, Lin, & Barr, 2003; Keysar, Barr, Balin, & Brauner, 2000), which examines real-world social reasoning using a referential communication game. Originally designed by Keysar and colleagues (2000; 2003), this task involves taking into account another person's perspective in order to guide decisions about selecting objects from a set of 4 x 4 shelves that are either visible (objects in open slots) or not visible (objects in occluded grey slots) to the 'director'. During the trials, the director asks participants to move certain objects around the shelves and critical instructions require the participant to use information about the director's perspective in order to correctly interpret their instructions. For example, when the director asks the participant to "move the small book down", he is referring to object (a) in Figure 4.1, which is the smaller of the two books mutually visible to him and the participant. He could not be referring to object (b), the smallest book visible to the participant, because he is unable to see that book, and does not know that it exists. Thus, when following the director's instruction, participants need to ignore irrelevant objects, such as object (b), which are valid referents from their own viewpoint, but not from the viewpoint of the director. Keysar et al., (2000; 2003) found that adults often failed to take into account the director's perspective when interpreting their instructions. Instead, around 50% of the time, participants incorrectly used their own (egocentric) viewpoint when trying to follow the director's instructions. These findings were also replicated and extended to younger participants by studies using computer-adapted versions of the paradigm (Apperly et al, 2010; Dumontheil et al, 2010).



**Figure 4.1 Example of the stimuli used in the director present condition**

The Director Task differs from other measures of ToM as it requires one to reason about another person’s viewpoint and intentions (the director), and to use this information in conjunction with executive control abilities (e.g., inhibiting prepotent responses to distractor objects, rule following, working memory etc.). This interaction between ToM and executive function enables one to overcome egocentric errors and select the appropriate object in a quick and accurate fashion (Apperly et al, 2010; Dumontheil et al, 2010). Of note, Dumontheil and colleagues (2010) suggest that the interaction between ToM and executive control continues to develop during the later stages of adolescence and is still vulnerable to egocentric errors in adulthood. Taken together, these findings demonstrate the Director Task as a sensitive index of complex mental-state reasoning, and highlight this communicative measure as a promising tool for assessing social and executive processing in a single paradigm.

Another example of a measure assessing social cognition in the context of executive control is the Emotional Face Go/No-Go (Hare et al., 2008; Tottenham et al., 2011). This computerised task incorporates facial stimuli into a classic Go/No-Go paradigm in order to examine how the rapid discrimination of basic emotions interacts with executive processing (Tottenham et al., 2011). For each block, participants are instructed to press a button every time a target emotional expression (e.g., happy) appears

on the screen ('go' trials) and to avoid pressing for any other expression ('no-go' trials). To assess inhibitory control in the presence and absence of positive (happy) and negative (sad, fear, and angry) emotions, each block consists of an emotional face being paired with a neutral face, which, depending on the block, either serves as the 'go' expression (neutral 'no-go') or the 'no-go' expression (neutral 'go'). A key advantage of the Emotional Face Go/No-Go task is that it can be used to assess executive control abilities under multiple emotional conditions (e.g., positive, negative, and neutral expressions), and help identify whether performance varies as a function of valence. Tottenham and colleagues (2011) administered this measure to a large sample of children, adolescents, and adults aged between 5 and 28 years. Data from this study revealed two key findings: (i) emotionally-relevant information can interfere with executive control processes, and that (ii) exercising inhibitory control in the presence of emotional stimuli improves with age. Of note, commission errors (or false alarm) to emotional 'no-go' faces did not differ in terms of valence, indicating that the presence of both positive and negative information is equally detrimental for task performance, relative to neutral distractors. However, whilst this pattern emerged across all age groups, the authors documented age-related decreases in false alarm rate to emotional 'no-go' expressions, suggesting that the ability to exert executive control in the context of affective information continues to improve into adulthood.

Using an adapted version of this task in their developmental study (aged 6 to 25 years), Schel and Crone (2013) reported a slightly different pattern of results. Whilst, the authors found an age-related decrease in overall false alarm rate, findings revealed that commission errors to emotional faces did not differ by trial type. In other words, performance did not differ based on whether the emotional faces were the go or no-go stimulus. Overall, these data indicate the Emotional Face Go/No-Go task as successful paradigm in assessing the interaction between affect and cognition, and demonstrate this measure as a valuable device for advancing our understanding of whether positive and negative emotions may differentially impact executive control abilities in normative and atypical development.



#### *4.1.2. Dual Assessment of Social Cognition and Executive Control in ASD*

Examining social information processing in the context of executive control is particularly relevant when considering interpersonal behaviour in ASD. As discussed in previous chapters, autism-related deficits in the interpersonal sphere have frequently been attributed to atypical neurocognitive profiles, such as impaired social cognition and difficulties in executive control (Lai et al., 2014). Indeed, studies examining these processes in autistic populations have often reported deficits in emotion recognition (Ashwin et al., 2006) and ToM ability (Dziobek et al., 2006), as well as in cognitive flexibility (e.g., Pellicano, 2007), response inhibition (Christ et al., 2007), planning (Lana & Goldberg, 2005), and working memory (Cui et al., 2010). Nonetheless, it is worth noting that typical performance across these domains have also been documented (e.g., Barnard et al., 2008; Edgin & Pennington, 2005; Goldberg et al., 2005; Jones et al., 2011; Ozonoff & Jensen, 1999; Ponnet, et al., 2004).

Whilst the observed inconsistencies may be a result of methodological variation and heterogeneity within ASD samples (e.g., presence of comorbid conditions), it may also reflect a lack of ecological validity. For instance, lab-based investigations of social cognition and executive control in ASD have typically examined these domains in isolation. However, given that socio-affective information and executive control frequently interact in everyday contexts (Schel & Crone, 2013) examining these processes separately is less likely to capture the demanding nature of real-world social interactions and is potentially misleading in autism research. Therefore, assessing social information processing in the context of executive control is likely to be a more fruitful approach to advancing our understanding of how these domains influence task performance in autistic and non-autistic populations. However, as with typical development, concurrent examination of these processes in ASD remains relatively sparse, limiting our understanding of the executive function and social cognition link in autistic individuals.

To date, only a handful of studies have simultaneously examined social and executive processing in ASD populations. One example of such a study is de Vries and Geurts 2012 investigation, which examined set-shifting abilities in the presence of emotional faces. To help bridge the gap between inflexible behaviour in real-world settings and laboratory-based measures of cognitive flexibility, the authors administered a gender emotion switch task to a sample of children with and without ASD (8-12 years). This computerised measure was adapted from the classical switch task (Rogers &

Monsell, 1995; White & Shah, 2006) and required participants to sort happy or angry looking male or female faces, based on gender or emotion. Switches between the two sorting rules occurred randomly and participants were presented with a cue indicating trial-type before each trial (e.g., happy and angry expressions for emotion trials, or a male/female symbol for gender trials). Findings showed that whilst overall task performance was comparable between the two groups, ASD children were slower when switching from emotion to gender trials than vice versa. This finding suggests that although children with ASD demonstrate typical performance on an ecologically valid switch task, they appear to experience difficulties in disengaging from an emotionally-relevant task set.

These data are somewhat surprising considering previous reports of impaired cognitive flexibility in lab-settings and frequent accounts of rigid and repetitive behaviour in everyday life. In an attempt to clarify these discrepant findings, de Vries and Geurts highlighted three possible explanations for the lack of group differences in flexible cognition. First of all, participants were informed that there would be rule switches at some point during the task and, thus, anticipated the shifts between emotion and gender trials. However, in real-world settings, we are required to flexibly adapt our behaviour in line with unexpected changes in our environment, and receive no forewarning about how or when these changes will occur. Therefore, although autistic individuals experience great difficulties in adapting to change, when warned or prepared, they are better able to modify their behaviour in response to novel situational demands (de Vries & Geurts, 2012; Meaden, Ostrosky, Triplett, Michna, & Fetting, 2011). Taken together, a switch task providing explicit rules may have failed to capture the complexities of navigating behaviour in real-life contexts and could have been too predictable for individuals with ASD.

Second, the authors propose that the task switch paradigm might provide an overly pure assessment of cognitive flexibility. Given that behavioural regulation in real-world settings requires multiple domains of executive control to work in concert, the refined nature of this paradigm may have reduced ecological validity and made the task less able to detect autism-related difficulties in flexible cognition (de Vries & Geurts, 2012). Lastly, whilst the use of facial stimuli improves ecological validity, the inclusion of basic emotions and the length of stimuli presentation may have failed to provide an adequate gauge of how cognitive flexibility interacts with socio-affective information in everyday contexts. For instance, in daily life, communicating with others requires one to process

and respond to expressions of emotion in a rapid and appropriate manner. These expressions range from basic emotions, such as fear and anger, to more complex emotions like embarrassment, pride, and envy. Emotional expressions also vary in terms of their intensity (e.g., strong to subtle expressions of anger), and may be fleeting, rather than last for extensive periods of time. Therefore, processing and generating appropriate responses to more complex or subtle expressions that are transient in nature is likely to place greater demands on cognitive flexibility, and may prove to be a challenging task even for those with more subtle impairments in this domain. Overall, this suggests that a task presenting fully-expressed basic emotions for a period of 2000 ms may be less sensitive to the autism-specific cognitive flexibility deficits impeding social performance in everyday life.

In addition to the task switch measure, the emotional face Go/No-Go paradigm has also been utilised in the context of providing a joint assessment of social and executive processing in ASD. Using this task Yerys and colleagues (Yerys, Kenworthy, Jankowski, Strang, & Wallace, 2013), found that in comparison to typically developing controls, children with high-functioning ASD had lower accuracy scores overall and made more impulsive responses when neutral faces were the 'Go' and emotional faces were the 'No-Go' stimuli. In contrast, an earlier investigation by Geurts, Beeger, and Stockmann (2009) found no significant differences in accuracy or speed between ASD children and matched controls. Whilst these findings indicate a mixed pattern of results, it should be noted that Geurts et al. (2009) employed a simpler version of this paradigm in which happy expressions were the 'Go' and angry faces were the 'No-Go' stimulus. However, in order to provide a comprehensive assessment of whether response inhibition in the presence of socio-affective information is intact, a common baseline condition of a neutral expression should be incorporated into the design and coupled with emotional expressions to form the 'Go' and 'No-Go' trials (Yerys et al. 2013). Given that Yerys et al. (2013) utilised a more wide-ranging form of the Emotional Face Go/No-Go task (identical to the version reported in Tottenham et al, 2011), their findings provide a clearer picture of the interaction between social and executive processing in ASD.

The interaction between ToM use and executive control has also been assessed in ASD populations via the Director Task. So far, however, findings from these investigations have been inconsistent with existing ToM literature. For example, Beeger and colleagues (Beeger, Malle, Nieuwland, & Keysar, 2010) found no evidence of impaired perspective-taking abilities in adults and adolescents with ASD. Likewise, using an adapted version of this task, Santiesteban et al., (Santiesteban, Shah, White, Bird, &

Heyes, 2014) reported comparable performance between ASD and typically developing controls, with both groups evidencing similar levels of egocentric errors during the critical trials. In contrast, however, a recent investigation by Abu-Akel and colleagues (2015) reported greater perspective-taking errors among those with higher ASD traits. One possible explanation for the divergent results may be that the Director Task provides a more structured and rule-driven assessment of social communication, which may alleviate some of the complexities associated with free-flowing reciprocal interactions (e.g., processing social cues from multiple modalities, and over-arousal from sensory input, Beeger et al., 2010) and allow high-functioning individuals with ASD to perform as successfully as typically developing controls.

One way of increasing complexity within the Director Task paradigm is to incorporate other aspects of everyday social interactions, such as multitasking whilst processing social information (Mills & Blakemore, 2014; Mills et al., 2015). Multitasking is a key feature of communication in real-world settings, as we often navigate social interactions whilst simultaneously keeping track of other, non-social information (Mills & Blakemore, 2014). Thus, by introducing a multitasking element and manipulating cognitive load (i.e., remembering either a single two-digit number [low cognitive load] or three two-digit numbers [high cognitive load]), this communicative measure is likely to provide a closer approximation of social information processing in real-world contexts and further our understanding of how keeping track of non-social information impacts communicative performance in participants with and without ASD. In sum, whilst findings from studies employing joint assessment tools are mixed, using more complex variants of these paradigms is likely to provide a better test of the link between social cognition and executive control, and provide a clearer picture on how these processes interact in typical and atypical development.

## **4.2 The Current Study**

Delineating the link between social cognition and executive control is essential to furthering our understanding of impaired social functioning in ASD. The use of ecologically valid paradigms indexing socio-affective processing in the context of executive control can be particularly helpful in this regard. However, despite a growing number of studies examining these processes via combined tasks in autistic populations,

findings have so far been mixed and limited by the predominant focus on high-functioning child samples. At present, there is a considerable paucity of research examining the interaction between social cognition and executive control in ASD adults, as well as in typically developing populations displaying elevated levels of autism traits.

To date, studies have reported increased social cognition (Chapter 3; Gökçen et al., 2014; Sasson, Nowlin, & Pinkham, 2013) and executive control difficulties (Chapter 3; Christ et al., 2010; Gökçen, et al., 2014) in adults with subclinical autism symptomatology, suggesting that these individuals may be more susceptible than the general population for ASD-related impairments and negative outcomes (e.g., poor social skills, peer rejection, loneliness, and mental health problems). Of note, a similar pattern emerged from a recent study examining social and executive processing concurrently in participants with high and low autism traits (Gökçen et al., 2014). This study incorporated emotional faces into a well-established cognitive flexibility paradigm based directly on the WCST. Participants were required to sort facial stimuli based on valence (positive vs. negative) and expressiveness (strong vs. weak), and were informed that they would need to rely on feedback (i.e., correct or incorrect) in order to learn by trial-and-error how to sort the cards correctly. There were a total of two unannounced rule-shifts and these occurred following 10 consecutive correct responses. Findings revealed that individuals with higher levels of ASD traits evidenced significantly poorer performance on this combined measure relative to their low trait counterparts. Taken together, these findings suggest that participants with higher levels of ASD traits experience significant difficulties in flexibly processing socio-affective information and yield further support for the hypothesis that these individuals may encounter qualitatively similar (though less severe) difficulties in social and executive processing as those diagnosed with ASD.

Whilst this line of research has produced findings of great value, studies have thus far primarily focused on assessing social and executive domains separately, leaving the potential interaction between these processes relatively underexplored. To our knowledge, there have only been two concurrent examinations of social cognition and executive control in relation to subclinical ASD traits (i.e., Abu-Akel et al., 2015; Gökçen et al., 2014). Given the link between autism symptomatology and ASD-related deficits in social and executive function (e.g., Chapter 3; Gökçen et al., 2014), there is need for a more comprehensive assessment of how typically developing individuals with elevated levels of autism traits process social information in the context of executive control. To this end, we

sought to provide a more detailed examination of these processes in typically developing adults by administering a detailed assessment of executive performance under multiple emotional conditions, and by employing a more complex version of the Director Task (i.e., the working memory variant). To our knowledge, this is the first study of its kind to utilise these measures in the examination of subclinical autism traits.

Although the literature is mixed with regards to whether individuals with ASD are impaired on measures combining social cognition and executive control, there is some evidence to suggest that high-functioning children with ASD (Yerys et al., 2013) and adults with elevated levels of ASD traits (Abu-Akel et al., 2015; Gökçen et al., 2014) experience difficulties in processing social information in the context of executive control. Therefore, based on these findings and the use of more complex task variants, individuals with higher levels of ASD traits were predicted to demonstrate poorer performance on measures providing a joint index of social cognition and executive control. Specifically, individuals with elevated levels of ASD traits were predicted demonstrate poorer performance when considering a different (i.e., director's) perspective (H1a) and this effect was expected to be more pronounced on trials performed under high, relative to low levels of cognitive load (H1b). With respect to the Emotional Face Go/No-Go task, it was hypothesised participants with higher ASD traits would be less adept at inhibiting prepotent behavioural responses (H2a), and that this effect would be particularly marked in the presence of emotional relative to neutral information (H2b).

In addition, given its high comorbidity with autism and reported associations with social cognition and executive control (Koven & Thomas, 2010; Lockwood, et al., 2013; Moriguchi, et al., 2006; Chapter 2), a secondary aim of this study was to evaluate the potential influence of alexithymia on measures providing a joint assessment of social and executive processing.

## 4.3 Methods

### 4.3.1 Participants

A total of 85 healthy adults were recruited through the University College London Psychology Subject Pool. Two participants were excluded from analyses due to missing data on one of the experimental tasks. This left a final sample of 83 participants (19% male) aged 18-31 ( $M= 19.55$ ,  $SD= 2.00$ ), with estimated IQ between 78 and 129 ( $M= 104.03$ ,  $SD= 10.32$ ). Participants provided written informed consent and were compensated with 2.5 course credits or £19 for their time.

### 4.3.2 Materials

#### 4.3.2.1 Assessment of autism symptomatology

Participants were assessed for autism traits using the 50-item Autism Spectrum Quotient (Baron-Cohen et al., 2001). Each statement is rated on a 4-point scale ranging from 'strongly agree' to 'strongly disagree'. Responses in the 'autistic' direction receive 1-point, whilst 'non-autistic' responses receive 0 points. Total scores range from a minimum of 0 to a maximum of 50, with higher scores indicating greater levels of autism symptomatology. The AQ has good construct validity and internal consistency (Cronbach's alpha .73 in the present study).

#### 4.3.2.2 Assessment of trait alexithymia

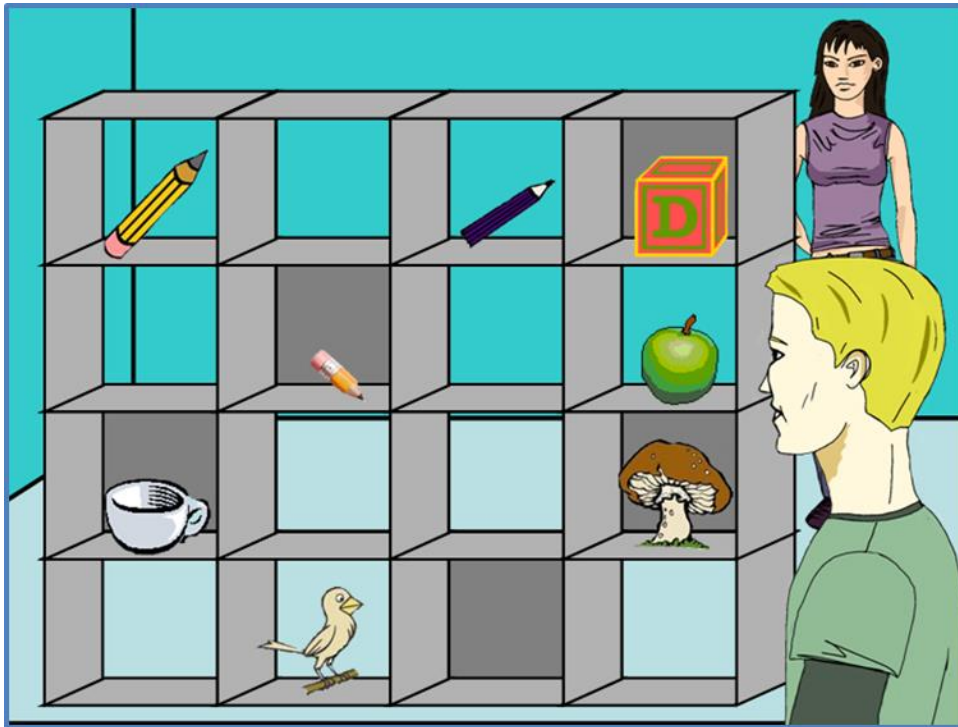
Alexithymic traits were assessed using the Toronto Alexithymia Scale (Bagby et al., 1994), a 20-item instrument comprising three dimensions: difficulty identifying feelings, difficulty describing feelings, and externally oriented thinking. Each item is presented on a five-point Likert scale (score, 1–5) ranging from "strongly disagree" to "strongly agree". Total scores vary from 20 to 100, with higher scores indicating a greater degree of alexithymia. The TAS has generally shown good psychometric properties (Bagby, et al, 2007; Cronbach's alpha 0.80 in the present study).

#### *4.3.2.3 Director task- working memory version*

A modified version of the “Director Task” (Dumontheil, Hillebrandt, Apperly, & Blakemore, 2012) with an embedded working memory component (Mills & Blakemore, 2014; Mills et al., 2015) was used to examine online use of ToM under cognitive load. This computer-based measure required participants to perform two tasks within each trial: one social and one non-social. The social component involved referential communication and required participants to interpret and use social cues to direct their choices, which at times involved making inferences about a different perspective. The non-social component of the task manipulated cognitive load by instructing participants to memorise numerical information in the form of a single two-digit number (low cognitive load) or three two-digit numbers (high cognitive load) displayed at the start of each trial. At the end of the social task, participants were presented with two numbers, one of which was shown at the start of the trial, and asked to select the option they recalled.

The stimuli for the social task consisted of a 4 x 4 set of shelves containing 8 different objects (see figure 4.2). There were two conditions: Director Present and No Director. In the Director Present condition, two directors, one female and one male, stood by the shelves. One director stood in front of the shelves and had the same view as the participant, whilst the other director stood on the opposite side of the shelves and had a restricted view, as five slots were occluded by a grey panel. During each of the trials, participants were presented with auditory instructions provided by either a male or female voice and required to use the computer mouse to move one of the objects presented on the shelves to a different slot, either one shelf up, down, left or right (this being the participants left or right). Participants then moved the mouse pointer from the middle of the computer screen and directed it towards the object they thought the director was referring to, clicked on the object and moved it to the relevant slot.

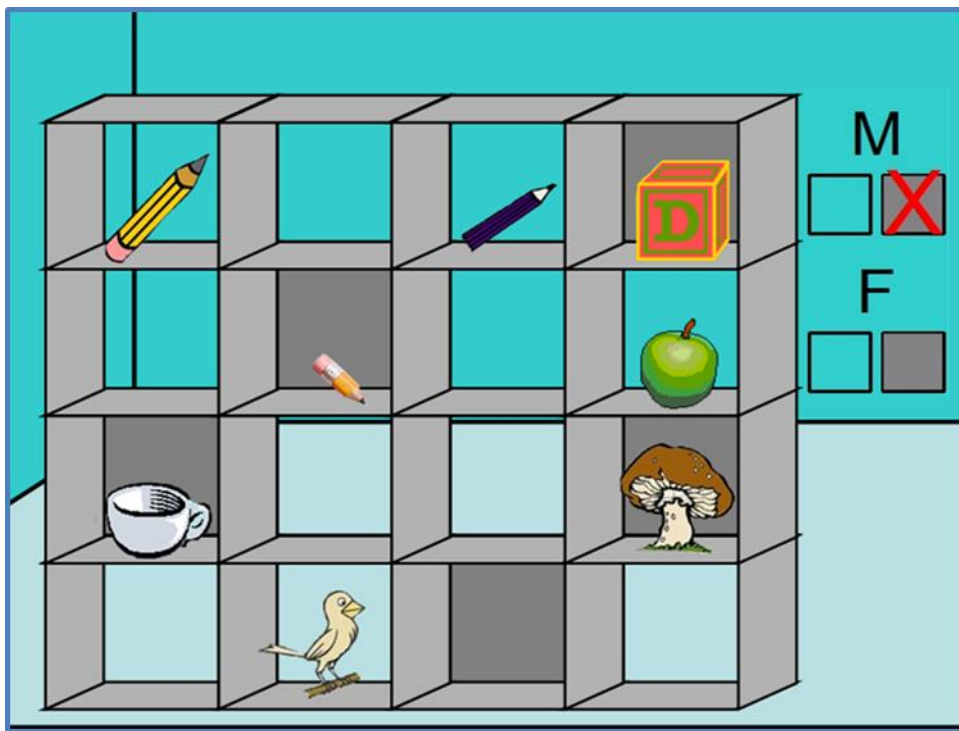




**Figure 4.2** Image depicting sample 'Director Present' trial.

In the No Director condition, the same auditory stimuli, shelves and objects were presented but without the director figures. Instead, the visual stimuli included the letter “F” for female and “M” for male, which were presented next to the shelves. Underneath each of the letters there were two boxes, one grey and one transparent. There was a red cross or a red circle over one of the grey boxes below either the letter “F” or “M”, which indicated that item-selection was restricted and that the objects in the grey slots could not be moved. For instance, if the instruction to move an object came from the male voice, then the participant was required to look at the boxes below the letter “M”, and if the grey box below this letter had a red cross, then the participant could only select the objects in the open slots. However, if there was no cross over the grey box, this indicated that there was no restriction on the participant’s choice and all eight objects were available for selection. Thus, in Figure. 4.3, if participants heard the male voice say: “Move the small pencil down” they would need to reason that, because the grey box below M has a cross over it, they could only select objects in the clear slots, and, thus, should ignore the yellow pencil in the grey shelf and select the blue pencil above. The consequences of these rules

were equivalent to the location of the director in the Director Present condition. In Director Present blocks, the physical position of the director providing the instruction varied on a trial-by-trial basis. Likewise, in the No Director blocks, the M/F rules also varied on a trial-by-trial basis.



**Figure 4.3** Image depicting sample ‘No-Director’ trial

Trials were also divided into 1- and 3-object blocks. Directives in 1-object filler blocks (e.g., in Figure 4.3, “Move the apple left”) referred to a single target object (there was only one apple), which was in an open shelf. In contrast, directives in 3-object experimental blocks (e.g., “Move the small pencil down”) could refer to an object in a closed shelf (with a grey background) or to an object in an open shelf. In the Director Present condition, the correct referent was ascertained by whether the director providing the instruction (identified as male or female by his or her voice) was standing at the front or back of the shelves, whilst in the No-Director condition, the location of the ‘X’ indicated which slots the participants could move objects from, which, again, was dependent on whether the instruction was delivered by the male or female (No Director). This task manipulation meant that in the Director Present 3-object trials, participants had

to take into account the director's viewpoint (which differed from their own viewpoint on half of the trials) in order to avoid selecting the irrelevant 'distractor' object. In the Director Present 1-object filler trials, the director's perspective had no impact on the accurate interpretation of his or her instructions. Consequently, participants were able to identify the correct object based on their own perspective on all trials. In contrast to the Director Present trials, the Director Absent trials did not require perspective-taking, as instructions are based on a simple rule and do not involve representing a different viewpoint.

Standardized instructions were read to participants and included example stimuli in which they had to state which objects should be moved for the different directors and voices. The task consisted of 16 blocks of 12 trials (8 blocks per Director Condition), and the order of blocks were counterbalanced across participants. The factors of interest included Cognitive Load (high vs. low load) and Perspective (Same vs. Different on 3-object trials in the Director Present condition).

This task was programmed using Cogent 2000 and Cogent Graphics ([www.vislab.ucl.ac.uk/cogent.php](http://www.vislab.ucl.ac.uk/cogent.php)) implemented in Matlab 6.5 (Mathworks, Inc., Sherborn, MA).

#### *4.3.2.4 Emotional Face Go/No-Go*

The Emotional Face Go/No-go (Hare et al., 2008; Tottenham, Hare, & Casey, 2011), a computerised measure that incorporates facial stimuli into a standard go/no-go paradigm, was used to assess response inhibition in affective contexts. This task required participants to press a button each time a target facial expression (e.g., sad faces) appeared on the screen. The stimuli set comprised 10 grayscale images of adults (five males and five females; Ekman & Friesen, 1976), modelling five different expressions (fear, anger, happy, sad, and neutral). Facial stimuli were presented individually in the centre of the screen and participants were instructed to press a button as fast and as accurately as they could when the target "Go" expression was displayed. The "go" trials were repeated more frequently (70% of the trials) in order to create a prepotency for responding. Participants were instructed to avoid responding to a "no-go" non-target expression (e.g., neutral face), which occurred less frequently (30% of all trials). Participants were not told what the "no-go" facial expressions were, but were instructed to avoid pressing for "any face other than the 'go' expression." In each block, an emotional face (happy, fear, angry, or sad) was

always coupled with a neutral face, and depending on the block, either the emotional faces served as the “go” stimulus (when neutral was the “no-go” stimulus) or as the “no-go” stimulus (when neutral was the “go” stimulus). Consequently, a total of eight randomised blocks of “go/no-go” pairs (happy–neutral, neutral–happy, fear–neutral, neutral–fear, angry–neutral, neutral–angry, sad–neutral, and neutral–sad), with 30 randomised trials for each condition were administered to participants. Each face stimulus was presented for 500ms, and participants were allowed 1000ms to make their response. Practice trials were administered to ensure that participants understood the task and were able to fulfil the response requirements. The main outcome variable of interest was False Alarm rate (i.e., errors of commission), which was calculated by summing the total number of errors for conditions when emotions (happy, sad, angry, fear) were the ‘Go’ and ‘No-Go’ stimuli. Total False Alarm rate was used as our index of overall behavioural control, and false alarm rate specifically to emotional ‘No-Go’ stimuli was our index of behavioural control in the presence of emotional information.

#### *4.3.2.5 General cognitive ability*

The two-subtest form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to produce an estimate of general cognitive ability. This includes assessment of vocabulary and matrix reasoning and provides an estimate of Full Scale IQ Scores (FSIQ).

#### *4.3.3 Procedure*

The study was granted ethical approval from UCL Division of Psychology and Language Sciences (PaLS) Ethics Committee (Ethics approval number CEHP/2014/525). Participants visited the testing laboratory for approximately 2.5 hours, completing the questionnaire measures first, followed by the computer tasks. All tasks were presented in randomised order and instructions were provided at the beginning of each test. Participants were tested individually and were allowed to take short rest breaks between the tasks as needed. After completing the test battery, participants were assessed for general intellectual ability using the two-subtest form of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999).

#### 4.4 Data Analyses

The study variables were visually inspected for normal distribution via QQ plots. Minor to moderate deviations from normality were detected for the following DTWM variables: error rates for overall different perspective trials, error rates different perspective trial performed under low cognitive load, error rates for same perspective trials, error rates for same perspective trials performed under low cognitive load, and RTs to different perspective trials performed under high cognitive load. Minor to moderate deviations to normality were observed for the following Emotional Go/No-Go variables: Happy 'Go', Sad 'Go', and Fear 'Go'. All remaining variables indicated approximate normality. According to the central limit theorem (Field, 2002), the distribution of sample means will be approximately normal regardless of the shape of the data provided that the sample size is sufficiently large ( $> 30$  or  $40$ ). Based on this criterion, the current data were deemed suitable for parametric analyses.

Bivariate correlation coefficients were conducted to examine the associations between ASD traits, alexithymia, and performance on concurrent measures of social and executive processing. With respect to the DTWM, two sets of analyses were conducted. First, mean percentage of errors for same and different perspective trials were calculated, as well as for same and different perspective trials performed under high and low levels of cognitive load. Second, reaction times to correct trials were analysed. Delayed responses ( $>9000$ ms) on the DTWM were excluded from the analysis (2.43% of all trials). Outliers (3 SDs from mean) were also calculated for each participants range of RTs and removed from analysis (1.24% of all trials), and mean correct RTs were calculated for same and different perspective trials, and for same and different perspective trials performed under high and low cognitive load. Two participants evidenced 100% errors on one of the task conditions and were subsequently eliminated from RT analysis. This left a final sample of 81 participants. The final set of analyses were conducted on total false alarm rates to emotional 'Go' and 'No-Go' faces, as well as overall false alarm rates.

Preliminary analyses revealed a significant negative correlation between IQ and accuracy scores on different perspective trials performed under low cognitive load ( $r = -.234$ ,  $p = .032$ ). All remaining associations between age ( $r < .087$ , all  $p > .439$ ), gender ( $r < .173$ , all  $p > .116$ ), and IQ ( $r < .143$ , all  $p > .201$ ) and task performance were non-significant.

## 4.5 Results

Descriptive statistics are presented in Table 4.1. Bivariate correlation coefficients between ASD traits, alexithymia, and behavioural measures are reported in Table 4.2.

**Table 4-1 Descriptive statistics**

<b>Outcome Variables</b>	<b>Mean</b>	<b>SD</b>	<b>Minimum</b>	<b>Maximum</b>
<b>Director Task: Director Present</b>				
<i>Error Rates (%)</i>				
Same Perspective	23.77	14.79	4.17	79.17
Different Perspective	24.44	17.81	0	95.83
Same Perspective Low Load	20.57	16.51	0	77.78
Same Perspective High Load	27.24	18.57	0	80
Different Perspective Low Load	18.05	20.35	0	100
Different Perspective High Load	30.16	19.88	0	93.33
<i>Reaction Times (ms)</i>				
Same Perspective	3322.19	561.17	2441.30	5461.92
Different Perspective	3922.96	591.78	2751.23	5806.67
Same Perspective Low Load	3291.00	584.84	2304.57	5469.13
Same Perspective High Load	3403.56	630.41	2387.90	5450.40
Different Perspective Low Load	3936.55	608.12	2513.87	5784.00
Different Perspective High Load	3921.25	717.17	2500.20	6283.25
<b>Emotional Face Go/No-Go</b>				
<i>Total False Alarm Rate to Emotion as 'No-Go'</i>				
Happy Faces	.82	1.17	0	8
Sad Faces	1.93	1.53	0	8
Angry Faces	1.40	1.26	0	5
Fearful Faces	.55	1.12	0	9
<i>Total False Alarm Rate to Emotion as 'Go'</i>				
Happy Faces	.69	1.29	0	9
Sad Faces	1.64	1.63	0	7
Angry Faces	1.14	1.13	0	4
Fearful Faces	.57	.84	0	3
<i>Total False Alarm Rate</i>	8.65	6.31	0	42

#### *4.5.1 Associations between autism traits, alexithymia, and concurrent measures of social and executive processing*

Once again, analysis revealed a positive correlation between ASD traits and alexithymia ( $r = .412$ ,  $p < .001$ ). There was also a significant positive correlation between ASD traits and slower RTs on different perspective trials performed under low levels of cognitive load. To further examine this association, a Steiger's Z-test was conducted on the correlations between ASD traits and different perspective trials performed under high and low levels of cognitive load. This test was significant ( $Z = 2.84$ ,  $p < .01$ ), suggesting that the correlations for different perspective trials performed under low load were significantly stronger than that for different perspective trials performed under high load.

Of note, the correlation between ASD traits and different perspective trials performed under low cognitive load remained significant once an outlier (identified as being 3 SDs away from the mean) was eliminated from the analysis ( $r = .368$ ,  $p = .001$ ). Once again, a Steiger's Z-test was conducted on the correlations between ASD traits and different perspective trials performed under high and low levels of cognitive load. This test was again significant ( $Z = 3.50$ ,  $p < .01$ ), suggesting that the correlations for different perspective trials performed under low load were significantly stronger than that for different perspective trials performed under high load.

None of the remaining correlations between the DTWM and ASD traits reached statistical significance. However, the correlation between ASD and RTs to different perspective trials indicated a trend towards statistical significance. With regards to the Emotional Face Go/No-Go task, ASD traits were positively associated with false alarm rates to angry faces when they were the 'Go' stimuli. No other significant associations between ASD traits and Emotional Go/No-Go performance were found. There were also no statistically significant correlations between alexithymia and performance on the DTWM. However, the positive association between trait alexithymia and false alarm rates to fearful faces when they were the 'No-Go' stimuli on the Emotional Go/No-Go task approached significance. Taken together, these findings yield partial support for hypothesis H1a, partial support for H2a, but fail to support hypotheses H1b and H2b. The



current sample size yielded adequate statistical power to detect moderate to large (Cohen, 1988) effects (power=.95), using two-tailed tests with alpha set at .05.

**Table 4-2 Correlations between ASD traits, alexithymia, and behavioural measures**

	ASD Traits	Alexithymia
<b>Director Task: Director Present</b>		
<i>Error Rates (%)</i>		
Same Perspective	.163 <i>p</i> = .140	.127 <i>p</i> = .252
Different Perspective	.004 <i>p</i> = .970	-.045 <i>p</i> = .683
Same Perspective Low Load	.135 <i>p</i> = .225	.059 <i>p</i> = .595
Same Perspective High Load	.175 <i>p</i> = .113	.157 <i>p</i> = .158
Different Perspective Low Load	.051 <i>p</i> = .650	.007 <i>p</i> = .952
Different Perspective High Load	-.066 <i>p</i> = .551	-.077 <i>p</i> = .487
<i>Reaction Times (ms)</i>		
Same Perspective	.080 <i>p</i> = .480	.005 <i>p</i> = .967
Different Perspective	.199 <i>p</i> = .075	.089 <i>p</i> = .431
Same Perspective Low Load	.028 <i>p</i> = .806	.039 <i>p</i> = .731
Same Perspective High Load	.109 <i>p</i> = .333	-.048 <i>p</i> = .672
Different Perspective Low Load	.315 <i>p</i> = .004	.107 <i>p</i> = .341
Different Perspective High Load	.075 <i>p</i> = .505	.031 <i>p</i> = .787
<b>Emotional Face Go/No-Go</b>		
<i>False Alarm Rate to Emotion as 'No-Go'</i>		
Happy Faces	.083 <i>p</i> = .455	.117 <i>p</i> = .293
Sad Faces	.029 <i>p</i> = .796	.005 <i>p</i> = .961

**Table 4.2 Continued**

	<b>ASD Traits</b>	<b>Alexithymia</b>
Angry Faces	.052 <i>p</i> = .640	.068 <i>p</i> = .541
Fearful Faces	.168 <i>p</i> = .128	.207 <i>p</i> = .061
<i>Total False Alarm Rate to Emotion as 'Go'</i>		
Happy Faces	.033 <i>p</i> = .768	.097 <i>p</i> = .384
Sad Faces	.025 <i>p</i> = .820	.017 <i>p</i> = .881
Angry Faces	.258 <i>p</i> = .019	.092 <i>p</i> = .407
Fearful Faces	.078 <i>p</i> = .481	.082 <i>p</i> = .460
<i>Total False Alarm Rate</i>	.137 <i>p</i> = .216	.131 <i>p</i> = .237

## 4.6 Discussion

The study described in this chapter set out to examine the relationship between ASD traits and concurrent measures of social cognition and executive control. Whilst literature is mixed with regards to whether individuals with ASD are impaired on measures assessing social and executive processing concurrently, there is some data indicating that high-functioning children with ASD (Yerys et al, 2013) and adults with elevated levels of autism traits (Abu-Akel et al, 2015; Gökçen et al, 2014) experience difficulties in processing social information in the context of executive control. Based on these findings, it was predicted that participants with higher ASD traits would evidence poorer performance on tasks assessing social cognition in the context of executive control. In addition, given the high comorbidity between ASD and alexithymia, and reported associations with social cognition and executive control (Koven & Thomas, 2010; Lockwood, et al, 2013; Moriguchi, et al, 2006; Chapter 3), a second aim was to examine the potential influence of this trait on measures assessing social and executive processing concurrently.

### 4.6.1 *Perspective-taking under cognitive load*

Accuracy data revealed non-significant associations between ASD traits and overall percentage of errors on same and different perspective trials, as well as non-significant associations with error rates for same and different perspective trials performed under high and low levels of cognitive load. With respect to RT data, higher levels of autism symptomatology was not associated with slower responses to same and different perspective trials. A similar pattern of findings emerged between ASD traits and same perspective trials performed under high and low levels of cognitive manipulation.

Findings did however indicate a positive association between elevated levels of ASD traits and slowed responses when accurately representing different perspectives under low cognitive load. In contrast to this result, there was no statistically significant association between autism symptomatology and different perspective trials performed under higher levels of manipulation. In light of the small sample size and relatively modest correlation coefficient, this should be considered a preliminary finding that requires further investigation. It is also worth noting that examining these processes in clinical populations may give rise to a clearer and stronger pattern of results given the more profound nature of

higher-order processing deficits. Nevertheless, in the current sample, these data may indicate a pattern of impairments unique to subclinical levels of ASD. For instance, whilst there may be a generic negative impact of high cognitive load on perspective-taking abilities, difficulties in processing information about another person's viewpoint under low cognitive load may be exclusive to typically developing individuals with higher levels of ASD traits.

This result is particularly interesting given that optimal social performance in real-world settings requires one to rapidly and accurately process a complex and continuous stream of social information. Furthermore, these social computations are often performed in settings where we are required to simultaneously process other, non-social forms of data (Mills & Blakemore, 2014; Mills et al., 2015). Therefore, given the intricate nature of everyday interactions, errors, or even more subtle delays in processing social information is likely to impede communicative performance and result in suboptimal social behaviour (e.g., inappropriate responses to others emotional states).

Taken together, this result appears consistent with recent findings documenting impaired Director Task performance among neurotypical adults with higher levels of ASD traits (Abu-Akel et al., 2015). The present study further extends these results by examining the ToM and executive function association under varying levels of cognitive load. Once again, it should be noted that this is a preliminary result that warrants further investigation in a larger sample of participants. However, it does tentatively suggest that individuals with elevated levels of ASD traits may be impacted by cognitive load manipulation while processing socially-relevant information in the context of executive control.

#### *4.6.2 Behavioural Control in the Presence of Affective Information*

Contrary to predictions, analysis revealed non-significant associations between ASD traits and false alarm rates on emotional 'No-Go' and neutral 'Go' trials. These findings suggest that inhibiting prepotent responses in the presence of socio-affective information is largely spared for neurotypical adults with elevated levels of autism symptomatology. A comparable pattern emerged on trials where emotional faces were the 'Go' and neutral faces were the 'No-Go' stimuli. However, findings did indicate a positive association between ASD traits and false alarm rates to angry faces during 'Go' blocks, suggesting impaired response inhibition in the presence of neutral information.

Given previous reports of ASD-related deficits on the Emotional Go/No-Go paradigm (Yerys et al., 2013), it is possible that these difficulties are present only in clinical cohorts with a diagnosis of ASD. However, this findings is somewhat surprising in light of previous data suggesting impaired emotional processing and response inhibition among those with higher levels of autism traits (Chapter 3). Thus, an alternative explanation for the lack of significant findings may lie in the task design. Although the Emotional Face Go/No-Go possess greater complexity and ecological validity relative to other variants (i.e., Geurts et al, 2009), it may require further adaptation in order to increase sensitivity to more subtle impairments that may be present at the subclinical level. For instance, the intricacy and ecological validity of this task could be further improved via shortened stimuli presentations and the inclusion of more subtle expressions of basic emotions, as well as more complex social emotions (i.e., embarrassment, pride, guilt etc.). At present, the Emotional Go/No-Go consists of extreme expressions of facial affect presented at 500ms. However, given that real-life interactions involve a wide range of affective states depicted at varying levels of intensity, incorporating these elements will help increase sensitivity to potential ASD-related difficulties in subclinical populations, and provide a closer approximation of social interactions in everyday contexts.

#### *4.6.3 Associations between concurrent measures of social and executive processing, and trait alexithymia*

Once again, the finding of a modest positive association between ASD traits and alexithymia replicated data reported in previous studies (Chapter 3; Lockwood et al, 2013). With regards to DTWM performance, analysis revealed no significant association with alexithymia. This finding is in line with previous reports suggesting intact perspective-taking abilities in those with elevated levels of this trait (i.e., Lockwood et al., 2013). While results Chapter 3 revealed a significant link between mentalising ability and alexithymia, these associations are likely to have resulted from the emotional content present the MASC and EYES tasks. Thus, given that the Director paradigm does not require interpretation of affective information, the lack of association with alexithymia does not come as a surprise. In terms of the Emotional Go/No-Go, however, the association between alexithymia scores and false alarm rate to fearful faces when they were the ‘No-Go’ stimuli indicated a trend towards significance. This finding suggests that

individuals with high alexithymic traits may experience greater difficulties in inhibiting prepotent responses in the presence of fearful affect.

#### *4.6.4 Limitations and future directions*

Some limitations of this research should be noted. Although our findings demonstrate ASD-related difficulties in perspective-taking abilities on the DTWM, these results emerged from a relatively small sample. Replication of these exploratory findings in larger neurotypical populations is therefore of particular importance. In addition, whilst the current study indicated sufficient power to detect moderate to large effect sizes, a sample of approximately 80 participants lacked statistical power to detect effects of a smaller size. Consequently, the non-significant associations between ASD traits, alexithymia, and our concurrent measures of social and executive processing should be interpreted with caution. As with previous chapters, there was a strong skew towards female participants, with less than 20% of the sample comprising males. Whilst analysis revealed no statistically significant confounding by gender, it would be preferable to examine these associations in a more balanced sample of participants. Finally, future examinations of these processes should also incorporate a battery of classic executive function measures in order to examine whether impairments on these integrative tasks were more pronounced relative to impairments in neutral measures of executive control. The incorporation of these tasks will help identify the potential ‘additive’ effects of socio-affective stimuli.

### **4.7 Conclusions**

This chapter describes a behavioural study which examined performance on concurrent measures of social and executive processing in relation to subclinical levels of autism traits. Preliminary findings indicate that in typically developing populations, elevated levels of ASD traits are associated with impaired performance on a referential communication task performed under varying levels of cognitive load. The finding of a non-significant association between alexithymia and DTWM performance further suggests that deficits on this paradigm are specific to autism symptomatology. By contrast, there was no evidence of ASD symptomatology being associated with poorer response inhibition in the presence of affective information. These preliminary results are an important step in advancing our understanding of the ASD-related social deficits

experienced in subclinical populations. In particular, they provide important insight into our understanding of how individuals with elevated autism traits are impacted by cognitive load when processing social cues in a communicative context. Indeed, examining social information processing in the context of executive control has proven sensitive to communicative impairments in adults with elevated autism symptomatology. Future investigations applying these tasks to clinical populations may considerably enhance our understanding of the social cognition and executive control interaction in ASD, as well as further our understanding of the broader autism phenotype. To this end, the next and final empirical chapter of this thesis presents an extension of this study to a sample of adults diagnosed with high functioning ASD.



## **5 Dual assessment of social and executive processing in adults with and without high-functioning ASD**

## 5.1. Chapter Introduction

Over the past three decades, social cognition and executive control have attracted considerable interest in autism research. Nonetheless, given that studies have primarily focused on assessing these domains separately, the potential interaction between social and executive processing remains relatively underexplored. To help rectify this gap in the literature, Chapter 4 examined whether subclinical levels of autism traits were associated with variability in processing socio-affective information in the context of executive control. Findings showed that in subclinical populations, elevated levels of ASD traits were associated with impairments on a referential communication task performed under varying levels of cognitive load. In addition, the finding of a non-significant association between alexithymia and Director Task performance corroborates the notion that performance deficits are specific to ASD. In contrast to the Director Task paradigm, there was no evidence of ASD symptomatology being associated with poorer response inhibition in the presence of affective information.

The current chapter sought to extend this line of enquiry to a sample of adults with high-functioning ASD. Using the task set from Chapter 4, this study investigated potential group differences between individuals with and without ASD, and examined whether performance deficits on combined paradigms were more pronounced relative to tasks assessing executive control in the absence of socio-affective information. Finally, the newly updated Autism Diagnostic Observation Schedule, Second Edition (ADOS-2; Lord, Luyster, Gotham, & Guthrie, 2012; Lord, Rutter, et al., 2012) was utilised to examine whether performance on combined and neutral tasks was related to diagnostic severity in the ASD group.

### *5.1.1 Dual assessment of Social Cognition and Executive Control in ASD: Summary of literature and findings*

As outlined in Chapter 4, successfully navigating our social environment is a demanding task, requiring continuous processing, updating, and interpretation of others' behaviour, as well as adjusting our own actions in line with varying situational demands. In addition to deciphering a stream of socially-relevant cues, everyday interactions also require the concurrent processing of non-social information (Mills & Blakemore, 2014).

The ability to perform these tasks in an effective and seamless fashion requires a suite of complex skills (e.g., maintaining attention, alternating between our own and others' perspectives, inhibiting inappropriate behaviours; Thornton & Conway, 2013; Ybarra & Winkielman, 2012), suggesting that other higher-order abilities may be integral to successful communication and adaptive social behaviour.

As discussed previously, increases in socio-affective processing demands may be supported by a set of generic executive skills, such as cognitive flexibility, working memory, and response inhibition. These higher-order functions allow one to monitor and modify ongoing behaviour in response to ever-changing situational demands (Corbett, et al., 2009; Gyurak, et al., 2009; Lezak, 1995; Lezak, et al., 2004), and frequently interact with socio-affective information in everyday settings (Schel & Crone, 2013; Tottenham et al., 2011). Indeed, in real-life situations, these cognitive processes rarely stand-alone, and we frequently employ executive control when navigating complex and multifaceted aspects of social interactions (Schel & Crone, 2013; Ybarra & Winkielman, 2012). Thus, given the close association between these domains, utilising paradigms which simultaneously assess social cognition and executive control may be particularly valuable in advancing our understanding of how they interact to facilitate optimal social performance. To date, however, studies examining these processes via dual assessment tasks remain relatively scarce.

Gauging socio-affective processing in the context of executive control can be particularly helpful when considering social functioning in autistic populations. Deficits in forming and maintaining interpersonal relationships, and a lack of social-affective reciprocity during interactions are cardinal features of ASD and widely documented across a myriad of studies. Of note, difficulties within the social realm are believed to be rooted in disrupted neurocognitive processes (such as social cognition and executive control, Lai et al., 2014). Nonetheless, whilst there is evidence to suggest atypicalities across social and executive domains (e.g., Ashwin et al., 2006; Dziobek et al., 2006; though also see Barnard et al., 2008; Goldberg et al., 2005; Jones et al., 2011; Ozonoff & Jensen, 1999; Ponnet, et al., 2004), studies have mainly taken a dichotomous approach in their examination and, consequently, provide limited insight into how they might interact. Given that executive control is primarily deployed in socio-affective contexts (Schel & Crone, 2013), examining these processes in tandem is likely to be a more promising method for advancing our understanding of the association between social and executive processing. To date, however, only a limited number of studies have employed dual

assessment techniques in autism research and these have so far revealed a mixed pattern of results, with some studies reporting ASD-related impairments (Gökçen et al., 2014; Yerys et al., 2013), and others not (Beeger et al., 2010; de Vries & Geurts, 2009; Santiesteban et al., 2014).

Taken together, whilst there has been a growing number of studies examining these processes via combined paradigms, findings have so far been inconsistent and there is clearly a need to further develop this line of enquiry to better understand the relationship between social cognition and executive control in ASD.

To this end, Chapter 4 of this thesis examined the social and executive processing link in relation to subclinical ASD traits using more complex variants of combined paradigms, such as the working memory variant of the Director Task and Emotional Face Go/No-Go. Findings showed that typically developing adults with elevated levels of autism traits were slower in taking a different perspective under low, relative to high levels of cognitive load. Whilst this finding is somewhat surprising, it may point to a pattern of impairments exclusive to subclinical levels of ASD. As discussed in the previous chapter, whilst there may be a generic negative impact of high cognitive load on perspective-taking abilities, difficulties in processing information about another person's viewpoint under low cognitive load may be specific to typically developing individuals with higher levels of ASD traits. Consequently, it is possible that the magnitude of impairments on this task may be considerably greater for those with a clinical diagnosis. Furthermore, the Emotional Go/No-Go paradigm may also impaired task performance in those with ASD.

Using the dual assessment tasks from Chapter 4, the current study sought to extend this line of enquiry to high-functioning adults with ASD. In addition, a series of neutral executive function tasks were administered in order to examine higher-order processing in the absence of emotional information. Last, the ADOS-2 (Lord et al., 2012; Lord, Rutter et al., 2012) was administered to determine whether performance on combined and neutral paradigms were related to diagnostic severity.

### *5.1.2 Associations between social cognition, executive control, and autism severity*

As discussed in the General introduction (Chapter 1), the key assumption underlying atypical neurocognition in ASD is that deficits within this sphere underlie its defining features (Lai et al., 2013). If this is indeed the case, then it is plausible to expect a significant association between impairments on concurrent measures of social and executive function and the severity of autism diagnosis. To investigate this prediction, participants' summary scores on the ADOS-2 were used as an index of symptom severity and correlated with performance on measures combining social and executive processing.

To date, few empirical studies have examined whether performance on tasks assessing social cognition and executive control is directly related to the defining features of autism. In one such study, Wallace and colleagues (2011) found that diminished sensitivity facial expressions of sadness were related to higher social and communication symptoms among adolescents with high-functioning ASD. In another, Tager-Flusberg (2003) found that ToM ability predicted scores on the social and communication domains of the ADOS, as well as the total score, independent of language level and IQ. Findings also showed that ToM performance explained a significantly higher proportion of the variance for ADOS communication than for ADOS social scores, even after accounting for the variance contributed by language. However, the correlation between ToM ability and repetitive behaviours and interests (as indexed by the ADI-R) did not reach statistical significance. Taken together, these data suggest that atypical ToM is directly related to symptom severity in communicative behaviour and social reciprocity, but not to repetitive behaviours and interests.

With respect to executive processing, South and colleagues (South, Ozonoff, & McMahon, 2007) revealed a positive correlation between perseverative responses on the WCST and repetitive behaviours on the ADOS and ADI-R. In contrast, a more recent investigation found no significant associations between parent reports of executive control on the Behavior Rating Inventory of Executive Function (Gioia, Isquith, Guy, & Kenworthy, 2000) and symptom severity in children and adolescents with ASD (van den Bergh, Scheeren, Beeger, Koot, & Geurts, 2014). These findings are somewhat surprising, given the number of reports suggesting ASD-related deficits in executive control. However, the lack of associations may be explained by the methodology used to index higher-order cognition. For instance, whilst self- and other-reports can yield valuable insight into executive difficulties encountered in real-life settings, their ability to tap

adequately the construct and explanatory power for autism severity may be limited. As a result, the inclusion of more complex behavioural measures is likely to provide a better assessment of the link between executive abilities and diagnostic severity.

So far, only one study has examined autism severity in relation to social cognition and executive control within the same study (Joseph & Tager-Flusberg, 2005). Findings showed that when non-verbal mental age was controlled, symptom severity across all three ADOS domains (communication, social, and repetitive behaviour and interests) were inversely related to ToM performance. However, after partialling out the effects of language ability, ToM was no longer related to social and repetitive behaviour symptoms. With regards to executive processing, findings showed that scores on the Knock-Tap (measuring response inhibition and working memory) and Tower (measuring planning ability) tasks were related to communication symptoms independent of nonverbal mental age. However, these correlations were no longer significant once language ability was controlled. Likewise, the negative correlation between Knock-Tap performance and repetitive behaviour symptoms remained significant after controlling for nonverbal mental age, but not once the variance for language ability was partialled out.

Furthermore, when examining the joint contribution of ToM and executive abilities to symptom severity, findings revealed that both ToM and planning performance were inversely related to communication symptoms in children with autism, and that these associations were independent of differences in language ability. In contrast, however, neither ToM nor planning ability were related to social and repetitive behaviour symptoms once the variance contributed by language ability was controlled.

Taken together, these findings demonstrate that impairments in social cognition and executive control are directly related to the severity of autism symptomatology. Specifically, they suggest that deficits in mental-state reasoning and executive control have a stronger association with communicative competence, than with social reciprocity and repetitive behaviours. In contrast, however, a more recent investigation by Yerys et al., (2013) documented no statistically significant association between Social and Communication scores on the ADOS and commission errors on the Emotional Face Go/No-Go in children with ASD. Instead, findings reveal that commission errors on this measure were significantly associated with ADHD symptomatology. In light of these findings, the authors concluded that impairments in regulating behaviour in the presence of emotional information may be a consequence of comorbid ADHD, rather than autism per se.

To summarise, whilst these studies provide valuable data on how atypicalities in social and executive processing map onto autism severity, two important gaps remain within the extant literature. First of all, studies examining these associations have primarily focused on children, leaving adult populations comparatively under-researched. Second, given that researchers have so far taken a dichotomous approach to the examination of social cognition and executive control, our understanding of how performance on combined paradigms relates to symptom severity remains considerably limited. To help rectify this gap, summary ratings from the ADOS-2 were utilised in order to relate performance on concurrent tests of social and executive processing to quantitative measures of autism severity. In addition to combined paradigms, the present study also examined whether performance on neutral measures of executive control would predict symptom severity across the domains of communication, social reciprocity, and repetitive behaviours and interests. This is the first study to provide a comprehensive examination of these associations in a sample of high-functioning adults with ASD.

### *5.1.3 The current study*

The aim of the current study was three-fold: (i) to examine whether high-functioning adults with ASD are characterised by impairments on ecologically valid tasks assessing social and executive processing simultaneously; (ii) to examine whether deficits on combined measures were more pronounced relative to neutral measures of executive control; and (iii) to assess whether performance on combined measures are related to ASD symptom severity across the ADOS domains of communication, social interaction, and total scores.

Although literature is mixed with regards to whether individuals with ASD are impaired on measures combining social cognition and executive control, there is some data to suggest that high-functioning children with ASD (Yerys et al., 2013) and adults with elevated levels of ASD traits (Abu-Akel et al., 2015; Gökçen et al., 2014) experience difficulties in processing social information in the context of executive control. With respect to symptom severity, there has been some empirical evidence to suggest that performance on measures of social cognition and executive control are directly related to the defining features of ASD (Joseph & Tager-Flusberg, 2004; South et al., 2007; Tager-Flusberg, 2003). Therefore, based on these findings, and the utilisation of more complex task variants, it was hypothesised that in comparison to typically developing controls,

adults with high-functioning ASD would demonstrate poorer performance on measures providing a joint index of social cognition and executive control. Namely, in comparison to neurotypical controls, individuals with ASD were predicted to demonstrate poorer performance when considering a different (i.e., director's) perspective (H1a), this effect was expected to be more pronounced on trials performed under high, relative to low levels of cognitive load (H1b). With respect to the Emotional Face Go/No-Go task, participants with ASD were predicted to be less adept at inhibiting prepotent behavioural responses (H2a), and this effect was predicted to be more pronounced in the presence of emotional relative to neutral information (H2b). In addition, the ASD group were also predicted to evidence markedly poorer performance on neutral measures of executive function (H3). However, deficits on these measures were expected to be less pronounced relative to deficits on combined paradigms (H4).

With regards to task performance and autism severity, it was predicted that poorer performance on combined measures would be related to greater symptom severity across all three ADOS-2 domains (H5). Significant associations between neutral measures of executive control and autism severity were also predicted, but these associations were expected to be less pronounced relative to those established with combined paradigms (H6).



## 5.2 Methods

### 5.2.1 Participants

Forty adult participants, 20 diagnosed with high-functioning ASD (8 female) and 20 typically developing gender-matched controls (8 female), were recruited for this study. ASD participants were recruited through email advertisements circulated via the National Autistic Society, AS Mentoring, and UCL Student Newsletter. All control participants were recruited through the PaLS Divisional Psychology Subject Pool. Participants were aged between 18 and 51 years (ASD:  $M = 19.36$  years,  $SD = .80$ ; controls:  $M = 16.67$  years,  $SD = .48$ ), with estimated IQ ranging from 87 to 129 ( $M = 105.30$ ,  $SD = 9.94$ ). There was no statistically significant difference in WASI scores ( $t(38) = <.1$ ,  $p = .595$ ) between the two groups, with the ASD group ( $M = 106.15$ ,  $SD = 8.04$ ) gaining comparable scores to controls ( $M = 104.45$ ,  $SD = 11.68$ ). As regards to age, analysis indicated significant group differences ( $t(38) = 4.26$ ,  $p <.001$ ), with ASD participants ( $M = 30.30$ ,  $SD = 9.23$ ) being significantly older than those in the control group ( $M = 20.95$ ,  $SD = 3.36$ ).

All participants in the ASD group were high-functioning and had previously received a diagnosis of autism or Asperger's Syndrome from an independent clinician according to the standard Diagnostic and Statistical Manual of Mental Disorders-IV criteria (American Psychiatric Association, 1994). Nineteen participants had received a diagnosis of Asperger's Syndrome and 1 of autism. Alongside the clinical diagnosis, we employed Module 4 of the ADOS-2 (Lord et al., 2012; Lord, Rutter et al., 2012) to further assess the current level of functioning for the ASD group (Table 5.1). On this measurement, three participants met ADOS criteria for autism and ten participants met criteria for autistic spectrum disorders. Seven participants scored above the cut-off point only in one of the two subscales. Typically developing controls did not exhibit autistic features and all scored below the clinical cut-off point on the AQ (32+; Baron-Cohen et al., 2001). Furthermore, analysis revealed significant group differences in AQ scores, with the ASD group ( $M = 33.75$ ,  $SD = 6.74$ ) gaining higher scores than the control group ( $M = 13.90$ ,  $SD = 4.84$ ; [ $t(38) = 10.69$ ,  $p = <.001$ ]).

Participants provided written informed consent and were compensated with either 2.5 course credits or £19 (controls). Participants in the ASD group received £7.50 per hour of participation and full reimbursement of all reasonable travel expenses incurred

**Table 5-1 Diagnosis and ADOS-2 scores**

Participant	Diagnosis	ADOS social interaction	ADOS communication	ADOS Total score
		Cut-off = 4	Cut-off = 2	Cut-off = 7
1	Autism	8	2	10
2	AS	4	3	7
3	AS	5	2	7
4	AS	5	2	7
5	AS	5	3	8
6	AS	5	1	6 <sup>a</sup>
7	AS	5	2	7
8	AS	8	3	11
9	AS	4	0	4 <sup>a</sup>
10	AS	5	6	11
11	AS	5	0	5 <sup>a</sup>
12	AS	6	3	9
13	AS	5	4	9
14	AS	5	2	7
15	AS	5	1	6 <sup>a</sup>
16	AS	5	4	9
17	AS	4	1	5 <sup>a</sup>
18	AS	5	0	5 <sup>a</sup>
19	AS	5	0	5 <sup>a</sup>
20	AS	6	2	8

*Note. The diagnosis refers to the original clinical assessment provided by a qualified psychologist or psychiatrist (AS = Asperger's syndrome). Scores on the ADOS-2 are derived from the diagnostic algorithm and represent the behaviour of the participant at the time of the study. a: Below cut-off on one ADOS-2 subscale.*

## 5.2.2 *Materials*

### 5.2.2.1 *Assessment of autism traits*

The Autism Spectrum Quotient (AQ; Baron-Cohen, Wheelwright, Skinner, et al., 2001) is a 50-item self-report questionnaire designed to quantify autism features in both clinical and community samples. Each statement is rated on a 4-point scale ranging from ‘strongly agree’ to ‘strongly disagree’. Responses in the ‘autistic’ direction receive 1-point, whilst ‘non-autistic’ responses receive 0 points. Total scores range from a minimum of 0 to a maximum of 50, with higher scores indicating greater levels of autism symptomatology. The AQ has x construct validity and internal consistency (Cronbach’s alpha .92 in the present study).

### 5.2.2.2 *Dual assessment of social cognition and executive function*

The Working Memory variant of the Director Task (Mills & Blakemore, 2014; Mills et al., 2015) and the Emotional Face Go/No-Go (Tottenham et al., 2011), described in the previous chapter, were used to provide a joint assessment of social cognition and executive control. Once again, our variables of interest from the Director Task was perspective (same vs. different) and cognitive load (high vs. low) in the Director Present condition. With respect to the Emotional Go/No-Go, our variable of interest was False Alarm rate (i.e., errors of commission), which was calculated by summing the total number of errors for conditions when emotions (happy, sad, angry, fear) were the ‘Go’ and ‘No-Go’ stimuli.

### 5.2.2.3 *Neutral measures of executive control*

With the exception of the Tower of London task, the executive function tasks did not differ from those reported in Chapters 2 & 3. Once again, cognitive flexibility was assessed via the WCST and OMO tasks, response inhibition was indexed via the Go/No-Go, and the N-Back was used to assess working memory (see previous chapters for detailed task descriptions).

#### *5.2.2.4 Assessment of general cognitive ability*

The two-subtest form of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to produce an estimate of general cognitive ability. This includes assessment of vocabulary and matrix reasoning and provides an estimate of Full Scale IQ Scores (FSIQ).

#### *5.2.3 Procedure*

The study was granted ethical approval from UCL Research Ethics Committee (Ethics approval number 3780/004), as well as the UCL PaLS Ethics Committee (Ethics approval number CEHP/2014/525). ASD participants visited the testing laboratory for approximately 3.5-4 hours, completing the questionnaire measures first followed by the ADOS-2 and computer tests. All tasks were presented in randomised order and instructions were provided at the beginning of each test. Participants were tested individually and were provided with short rest breaks between each task. After completing the test battery and ADOS assessment, participants were administered the two-subtest form of the Wechsler Abbreviated Scale of Intelligence (Wechsler, 1999), to produce an estimate of general cognitive ability. With the exception of the ADOS-2 measure, control participants were administered the same battery of tasks and completed the session in 2.5 hours.

## 5.3 Results

### 5.3.1 Preliminary Analyses

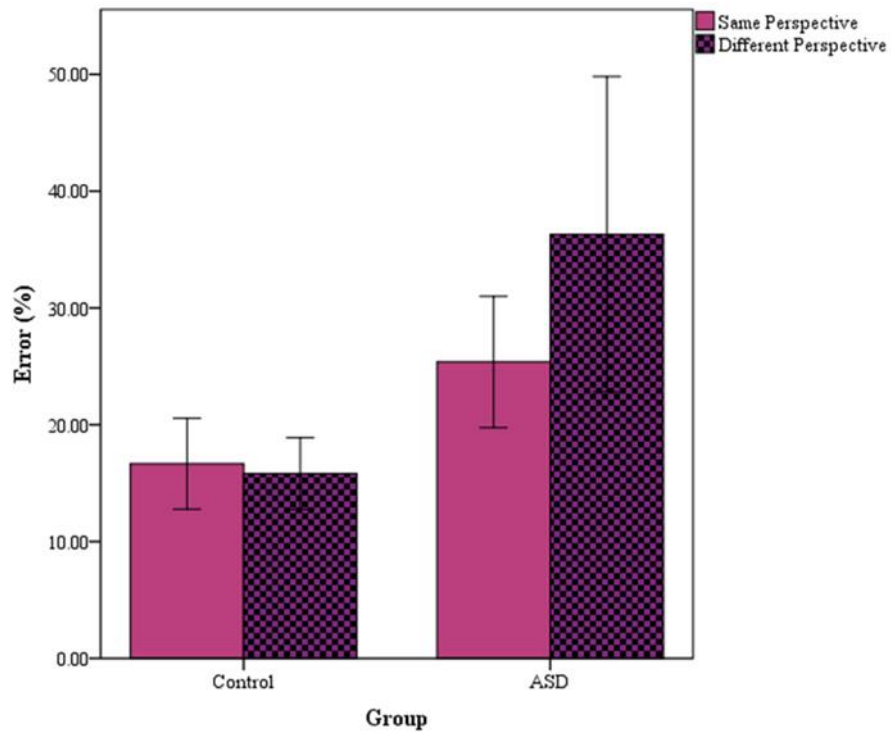
All study variables were graphically assessed for normal distribution via QQ plots. Minor to moderate deviations from normality were detected for a number of study variables. However, given that ANOVAs are robust to minor/moderate deviations from normality (Glass, Peckham, & Sanders, 1972; Lix, Keselman, & Keselman, 1996; Stevens, 2002), the use of parametric tests were deemed to be justified. Additionally, examination of box plot graphs revealed one non-ASD participant as an outlier on the Emotional Go/No-Go and N-Back tasks. Analyses for these measures were, therefore, performed with and without the outlier in order to identify whether this observation has undue influence on the results.

### 5.3.2 Director Task-Working Memory version

*Accuracy data.* Participants evidenced 89% accuracy on Filler trials on average, and the data for these trials were excluded from further analyses. Preliminary analyses indicated significant associations between DTWM performance and age. Therefore, age was incorporated into the model as a covariate. To test hypothesis 1a, percentage of errors for each perspective type was calculated for each participant and analysed using a 2 (Perspective: Same vs. Different) x 2 (Group: ASD vs. Control) mixed model repeated-measures ANCOVA, controlling for age. Mean percentage of errors were calculated for each group (see Table 5.2 and Figure 5.1).

There was no main effect of Perspective ( $F(1, 37) = .814, p = .373$ , observed power = .14). However, a main effect of Group was observed ( $F(1, 37) = 4.41, p = .043, \eta^2 = .11$ , observed power = .53), such that ASD participants were overall less accurate in interpreting social cues relative to typically developing controls. The two-way interaction between Perspective and Group ( $F(1, 37) = 3.46, p = .071, \eta^2 = .09$ , observed power = .44) approached significance, suggesting that accuracy on same and different perspective trials was different for participants with and without ASD. Inspection of Table 5.2 and Figure 5.1 demonstrates that participants in the ASD group evidenced more errors on different than same perspective trials, whilst controls made a similar number of errors across both trial types.

Finally, age had no effect in the model ( $F(1, 37) = .856$   $p = .361$ , observed power = .15).



**Figure 5.1 Mean percentage of error rates for ASD and Control participants as a function of same and different perspective trials.**

*Error bars represent standard errors.*

**Table 5-2 Mean percentage of error rates and reaction times to correct trials for ASD and Control participants as a function of same and different perspective trials.**

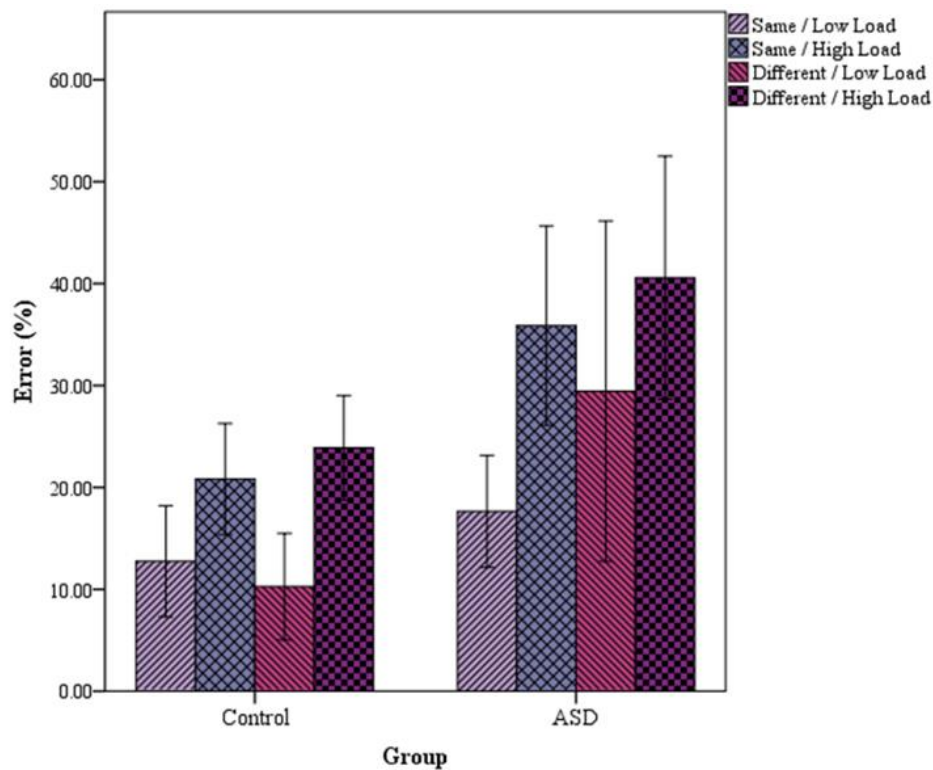
Perspective	Autism Spectrum Disorder		Control	
	Error (%)	RT ( <i>ms</i> )	Error (%)	RT ( <i>ms</i> )
Same	25.42 (12.01)	3845.22 (694.76)	16.67 (8.33)	3095.22 (435.39)
Different	36.25 (28.87)	4537.39 (669.78)	16.46 (7.82)	3674.56 (563.78)

Next, the effect of cognitive load on perspective taking ability was examined via two separate analyses. First, we performed a 2 (high vs. low Cognitive Load) x 2 (ASD vs. Control) mixed model ANCOVA (controlling for age) on different perspective trials alone. Findings revealed no main effect of Cognitive Load ( $F(1, 37) = .<.01, p = .900$ , observed power= .05), and the two-way interaction between Cognitive Load and Group ( $F(1, 37) = .808, p = .374$ , observed power= .14) also failed to reach statistical significance. However, there was a main effect of Group ( $F(1, 37) = 4.65, p = .038, \eta^2 = .11$ , observed power= .56), with ASD participants overall demonstrating a greater percentage of errors on different perspective trials compared to neurotypical controls (see Table 5. 3 and Figure 5.2). As before, there was no effect of age ( $F(1, 37) = .<.1, p = .986$ , observed power= .05).

A similar 2 x 2 mixed model ANCOVA performed on same perspective trials alone revealed no main effect of Cognitive Load ( $F(1, 37) = .141, p = .709$ , observed power= .07), and there was also no significant two-way interaction between Cognitive Load and Group ( $F(1, 37) = .837, p = .366$ , observed power= .15). No main effect of Group ( $F(1, 37) = 2.70, p = .109$ , observed power=.36), suggesting that both ASD and non-ASD participants evidenced similar levels of accuracy on same perspective trials (see Table 5.3 and Figure 5.2). Last, there was no effect of age in the model ( $F(1, 37) = 2.41, p = .129$ , observed power= .33).

Taken together, findings from accuracy data suggest that regardless of cognitive load, considering another person’s viewpoint is particularly difficult for participants with ASD, relative to typically developing controls.





**Figure 5.2 Mean percentage of error rates for ASD and Control participants as a function of trial type and load**

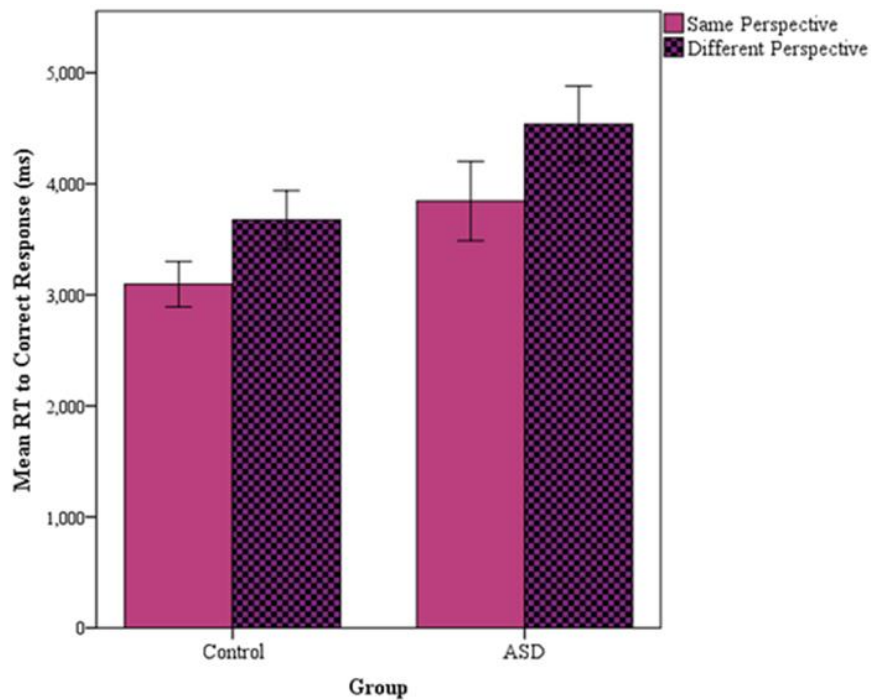
*Trial types: same and different perspective, performed under high and low cognitive load. Error bars represent standard errors.*

*Reaction Times.* Delayed (>9000 ms) responses (5.5%) were excluded from reaction time (RT) analysis. Outliers (3 SDs from the mean) were also calculated for each participant's range of RTs and removed from analysis (1.8% of total trials), and mean RTs from correct responses were calculated for each participant. Participants with no correct response in one of the conditions were omitted from the analysis (resulting group sizes: ASD = 17 and Control = 20). Mean RTs were calculated for each group (see Table 5.2 and Figure 5.3). A 2 (Perspective: Same vs. Different) x 2 (Group: ASD vs. Control) mixed-model ANCOVA, controlling for age was performed on RT data. Findings revealed a main effect of Perspective ( $F(1, 34) = 9.59, p = .004, \eta^2 = .22$ , observed power = .85), with participants evidencing slower RTs when responding to Different, relative to Same perspective trials. There was no significant interaction between Perspective and Group ( $F(1, 34) = .725, p = .401$ , observed power = .13). However, a main effect of group was observed ( $F(1, 34) = 8.26, p = .007, \eta^2 = .20$ , observed power = .80), such that participants

with ASD were overall slower in responding to correct trials, relative to neurotypical controls. No effect of age was observed ( $F(1, 34) = 1.41, p = .243$ , observed power= .21).

**Table 5-3 Mean percentage of error rates and reaction times to correct trials for ASD and Control participants as a function of same and different perspective trials performed under high and low cognitive load.**

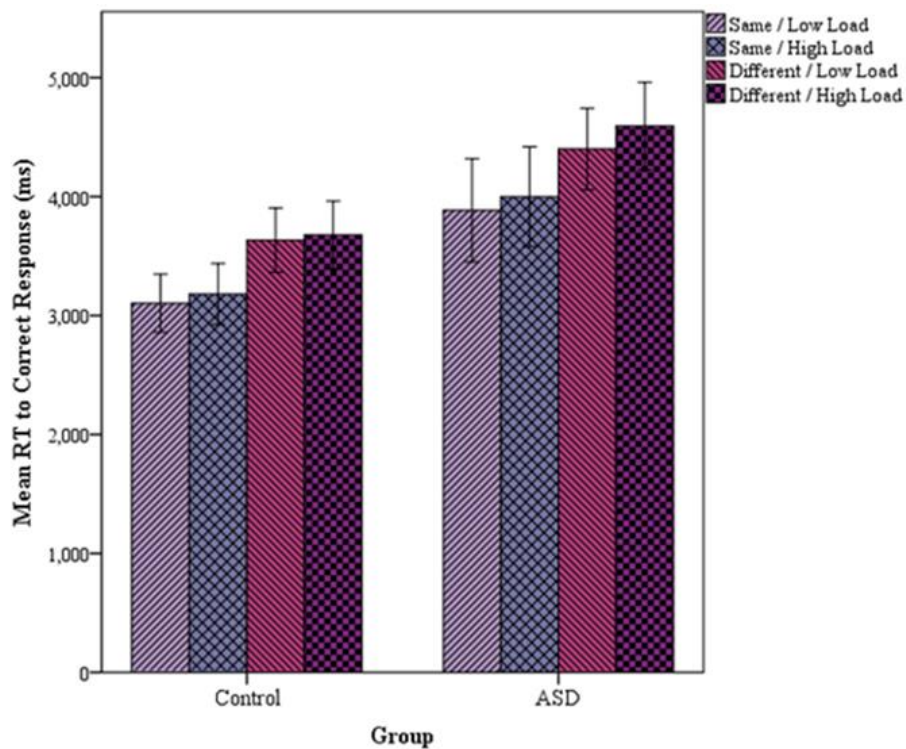
		Autism Spectrum Disorder (N=20)		Control (N=20)	
Perspective	Cognitive Load	Error (%)	RT (ms)	Error (%)	RT (ms)
Same	Low	17.55 (11.64)	3885.14 (844.12)	12.66 (11.51)	3103.56 (522.29)
	High	35.89 (20.89)	3999.26 (816.38)	20.79 (11.70)	3180.56 (547.82)
Different	Low	29.44 (35.70)	4400.89 (666.98)	10.23 (11.17)	3633.12 (576.77)
	High	40.59 (25.45)	4593.60 (716.24)	23.98 (10.89)	3677.96 (608.03)



**Figure 5.3 Mean RTs for ASD and Control participants as a function of same and different perspective trials.**

*Error bars represent standard errors.*

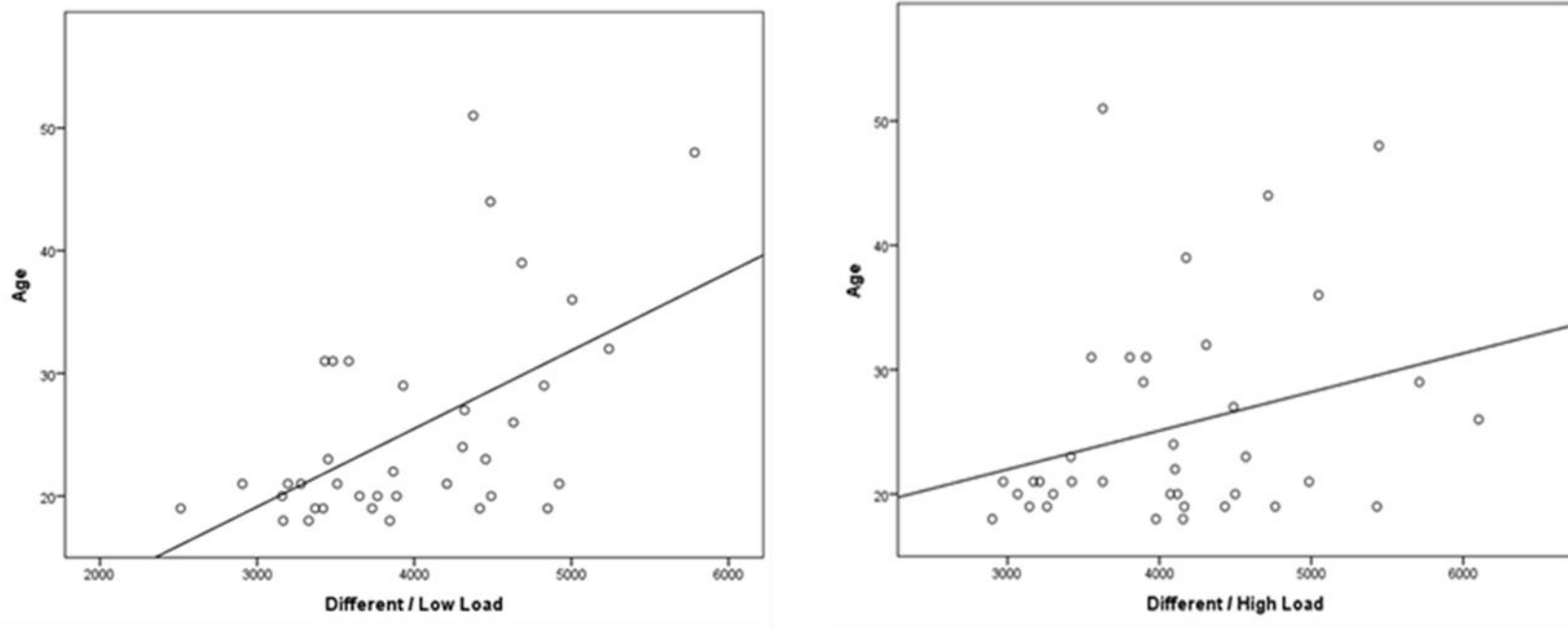
Next, the effect of cognitive load on RTs to correct trials were examined via two separate analyses. First, we performed a 2 (high vs. low cognitive load) x 2 (ASD vs. Control) mixed model ANCOVA on RTs to correct different perspective trials alone. Findings revealed a main effect of Cognitive Load ( $F(1, 34) = 7.76, p = .009, \eta^2 = .19$ , observed power = .77), with participants evidencing slower RTs to Different perspective trials performed under high than low cognitive load. This was qualified by a significant Cognitive Load by Group interaction ( $F(1, 34) = 4.37, p = .044, \eta^2 = .11$ , observed power = .53), indicating that RTs to Different perspective trials performed under high and low cognitive load differed for participants with and without ASD. Inspection of the data (see Table 5.3 and Figure 5.4) shows that although RTs to correct different perspective trials were slower under high load across all participants, this effect was more pronounced for individuals with ASD. This suggests that ASD participants are more susceptible than controls to the effects of increased cognitive load whilst adopting another person's viewpoint. There was also a main effect of group ( $F(1, 34) = 10.47, p = .003, \eta^2 = .24$ , observed power = .88), such that participants with ASD had longer RTs to correct responses overall than typically developing controls.



**Figure 5.4 Mean RTs to correct responses for ASD and Control participants as a function of trial type and load**

*Trial types: same and different perspective, performed under high and low cognitive load. Error bars represent standard errors.*

Overall, no effect of age was observed in the model ( $F(1, 34) = .746, p = .394$ , observed power = .13). However, there was a significant Cognitive Load by Age interaction ( $F(1, 34) = 6.47, p = .016, \eta^2 = .16$ , observed power = .70). Inspection of Figure 5.5 suggest that older participants evidenced slower responses on different perspective trials performed under low load, relative to high cognitive load.



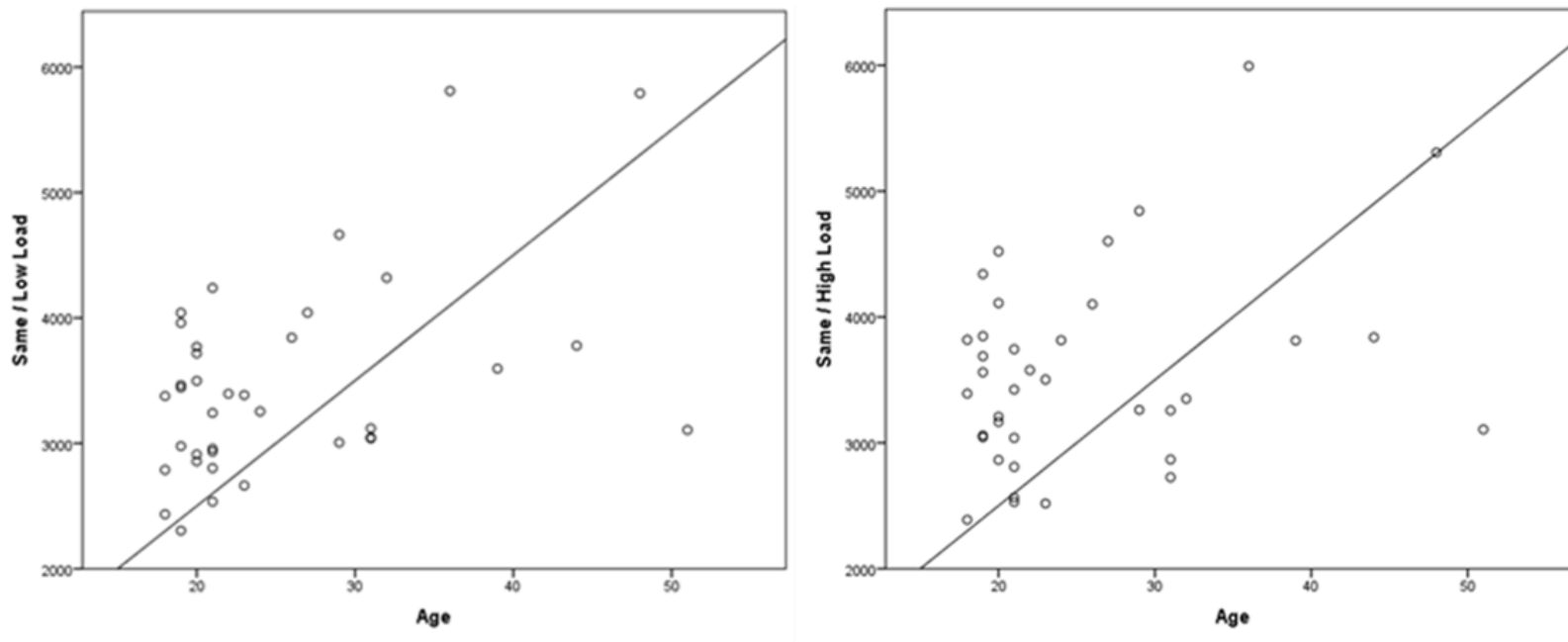
**Figure 5.5** Associations between age and mean RTs to correct different perspective trials performed under low and high cognitive load

A similar 2 x 2 mixed model ANCOVA computed on same perspective trials alone revealed a main effect of Cognitive Load ( $F(1, 34) = 5.47, p = .025, \eta^2 = .14$ , observed power = .62), with participants evidencing slower RTs to Same perspective trials performed under high, relative to low cognitive load. There was a non-significant interaction between Cognitive Load and Group ( $F(1, 34) = 1.92, p = .175$ , observed power = .27). As before, there was a main effect of Group ( $F(1, 34) = 6.56, p = .015, \eta^2 = .16$ , observed power = .70), with ASD participants demonstrating slower RTs to correct trials overall, compared to neurotypical controls.

Once again, there was no effect of age in the model ( $F(1, 34) = .717, p = .403$ , observed power = .13). However, a significant Cognitive Load by Age ( $F(1, 34) = 4.13, p = .050, \eta^2 = .11$ , observed power = .51) interaction was observed. Inspection of Figure 5.6 suggest that older participants had slower responses to same perspective trials performed under low, relative to high cognitive load.

To summarise, RTs to correct responses were slowest to different perspective relative to same perspective trials across both participant groups. In addition, findings showed that processing social cues under high levels of cognitive load incurred performance deficits for both groups. However, this effect was more pronounced for ASD than non-ASD participants, particularly when the task involved considering another person's viewpoint. With regards to the age by cognitive load interactions, the present findings also suggest that older participants are slower in responding to same and different perspective trials whilst under low levels of cognitive load.

Overall, these findings yield strong support for hypotheses H1a and H1b.



**Figure 5.6 Associations between age and mean RTs to correct same perspective trials performed under low and high cognitive load.**

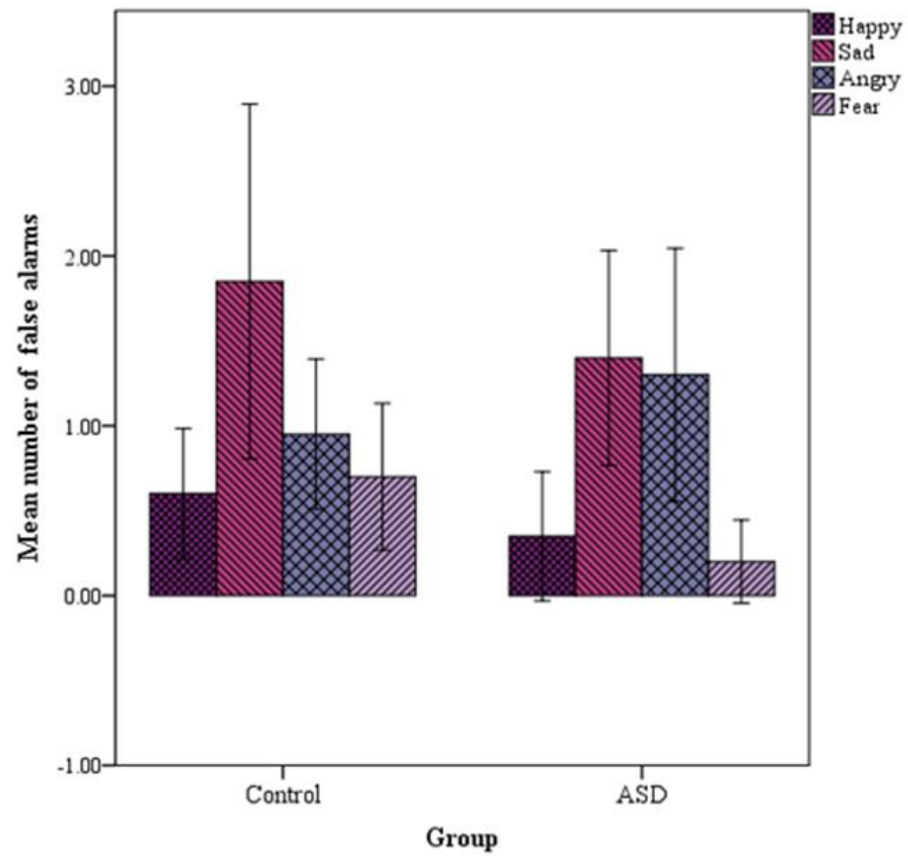
### 5.3.3 Emotional Face Go/No-Go

To test Hypotheses 2a and 2b, False alarm errors for each experimental condition was calculated for each participant and analysed using a 2 (Trial type: emotions as ‘Go’ and ‘No-Go’) x 4 (Emotion: Happy, Sad, Angry, and Fear) x 2 (Group: ASD and Control) mixed-model ANOVA. Mean false alarm rates were calculated for each group (see Figures 5.7 and 5.8). A main effect of Trial Type was observed ( $F(1, 38) = 14.77, p < .001, \eta^2 = .28$ , observed power = .96), with participants conducting more false alarm errors when emotional expressions were the ‘No-Go’ stimuli compared to when neutral faces were the ‘No-Go’ stimuli (i.e., emotional ‘go’ trials). Analysis also revealed a main effect of emotion (Greenhouse-Geisser corrected  $F(2.28, 86.48) = 21.32, p < .001, \eta^2 = .36$ , observed power = .1.0). Post-hoc pairwise comparisons (Bonferroni corrected) indicated that false alarm rates were higher for sad relative to fear (mean difference = 1.45,  $p < .001$ ), happy (mean difference = 1.36,  $p < .001$ ), and angry (mean difference = .838,  $p = .006$ ) expressions. False alarm rates were also found to be higher for angry relative to happy (mean difference = .538,  $p = .020$ ) and fearful (mean difference = .613,  $p = .043$ ) expressions. There were no difference in false alarm rates between happy and fearful expressions (mean difference = .075,  $p = 1.0$ ).

There was no main effect of group ( $F(1, 38) = .132, p = .718$ , observed power = .07), and no significant interaction between Emotion and Group ( $F(3, 114) = .618, p = .562$ , observed power = .16) or between Trial Type and Emotion ( $F(3, 114) = 1.32, p = .271$ , observed power = .33). The three-way interaction between Trial Type, Emotion, and Group ( $F(3, 114) = 1.82, p = .148$ , observed power = .34) was also non-significant, however the Trial Type by Group ( $F(1, 38) = 3.25, p = .079, \eta^2 = .08$ , observed power = .42) interaction indicated a trend towards significance. Of note, this interaction becomes significant following the removal of an outlier from the non-ASD group ( $F(1, 37) = 6.00, p = .019, \eta^2 = .14$ , observed power = .67). This suggests that false alarm rates to emotional ‘Go’ and ‘No-Go’ trials differed for ASD and Control participants. Removal of the outlier revealed no further changes in the model. Inspection of Figure 5.7 shows that both ASD and Control groups evidenced a similar false alarm rate when neutral faces were the ‘No-Go’ stimuli. However, Figure 5.8 shows that on trials where emotional faces were the ‘No-Go’ stimuli, the ASD group

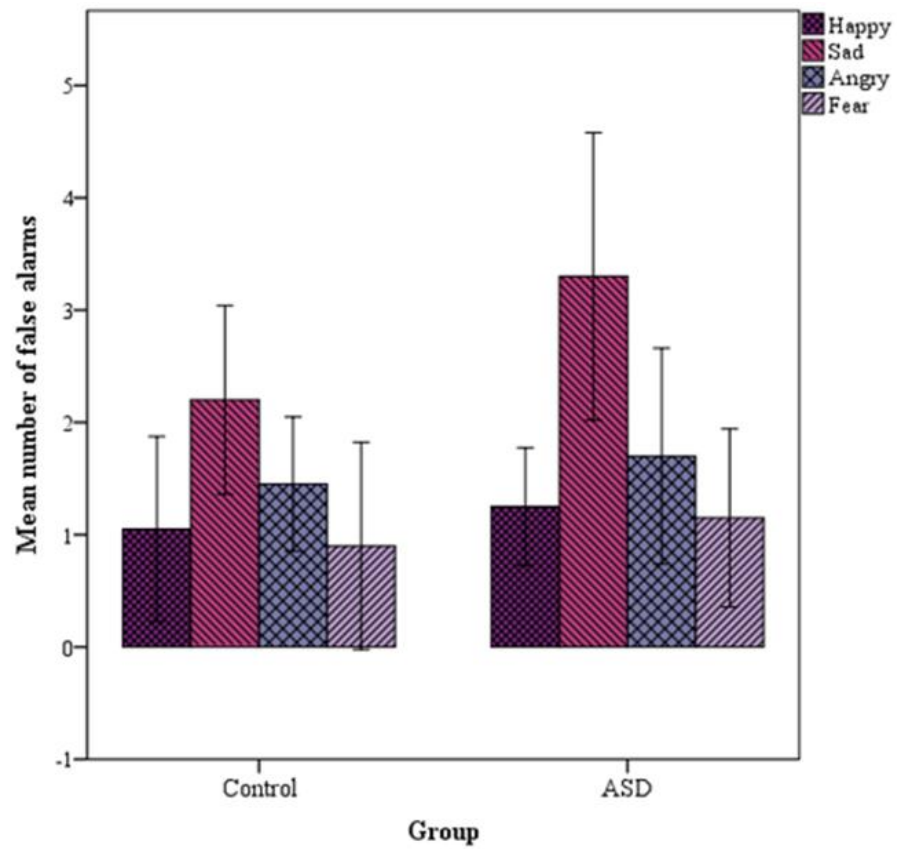


made more errors, suggesting that individuals with ASD may be less able to inhibit a pre-potent behavioural response in the presence of affective information.



**Figure 5.7** Mean number of False Alarms for ASD and Control participants as a function of Emotion ‘Go’ trials.

*Error bars represent standard errors.*



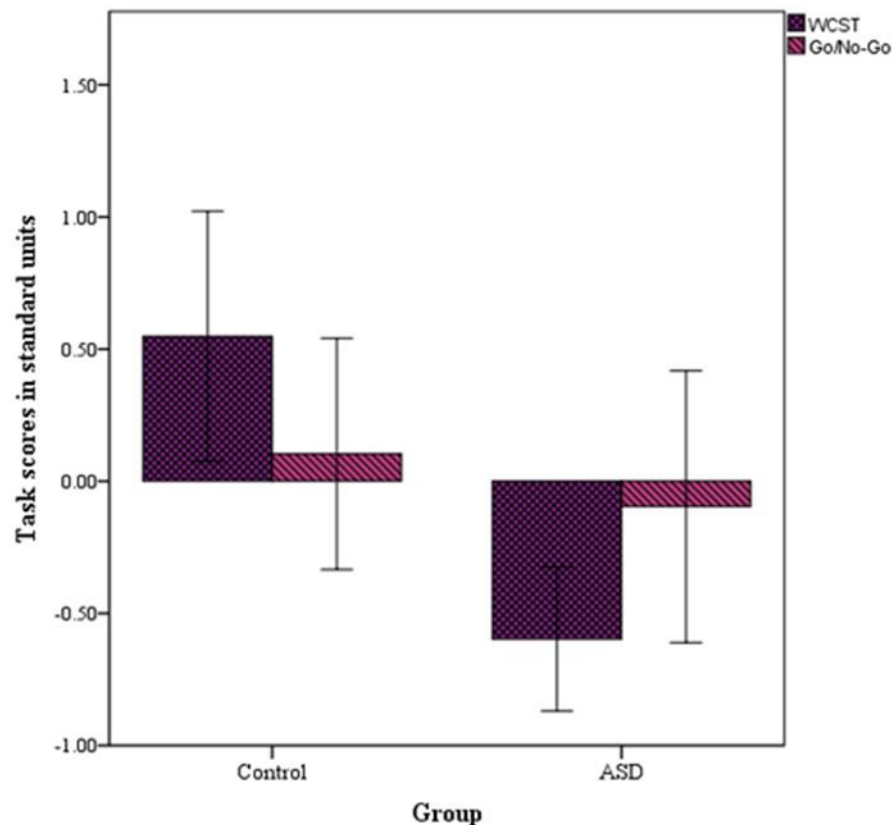
**Figure 5.8 Mean number of False Alarms for ASD and Control participants as a function of Emotion ‘No-Go’ trials.**  
*Error bars represent standard errors.*

### 5.3.4 *Neutral measures of executive function*

#### 5.3.4.1 *Cognitive flexibility and response inhibition*

To test H3, multivariate analyses were used to examine group differences in cognitive flexibility and response inhibition. Scores on the WCST and Go/No-Go tasks were entered as dependent variables, participant group (ASD vs. Controls) was entered as the independent variable. Preliminary analyses indicated significant associations between task performance and age. Therefore, age was incorporated into the model as a covariate. The effect of group was significant, ( $F(2, 36) = 4.11, p = .025, \eta^2 = 0.19$ , observed power = .10; see Figure 5.9.), with the ASD group demonstrating poorer executive control than non-ASD controls.

Inspection of follow up ANOVAs revealed a significant effect of group on the WCST test ( $F(1, 37) = 8.13, p = .007, \eta^2 = 0.18$ , observed power = .79), with the ASD group ( $M = 15.45, SD = 10.89$ ) demonstrating poorer performance relative to typically developing controls ( $M = 36.90, SD = 18.93$ ). However, with respect to Go/No-Go performance, analysis returned a non-significant effect of group, ( $F(1, 37) = .086, p = .771$ , observed power = .06) with ASD ( $M = 12.50, SD = 9.35$ ) and control participants evidencing similar rates of commission errors ( $M = 14.20, SD = 7.95$ ). Finally, the covariate, age, revealed no significant effect in the model (WCST:  $F(1, 37) = 2.05, p = .161$ , observed power = .29; Go/No-Go:  $F(1, 37) = 2.03, p = .163$ , observed power = .28).



**Figure 5.9 Mean scores for ASD and Control participants on measures of cognitive flexibility and response inhibition.**

*Error bars represent standard errors. Graph is based on standardized dependent variables.*

#### 5.3.4.2 Further assessment of cognitive flexibility

Due to time limitations, data from OMO task could not be included in the current chapter. However, analysis will be completed and incorporated into the manuscript submitted for publication.

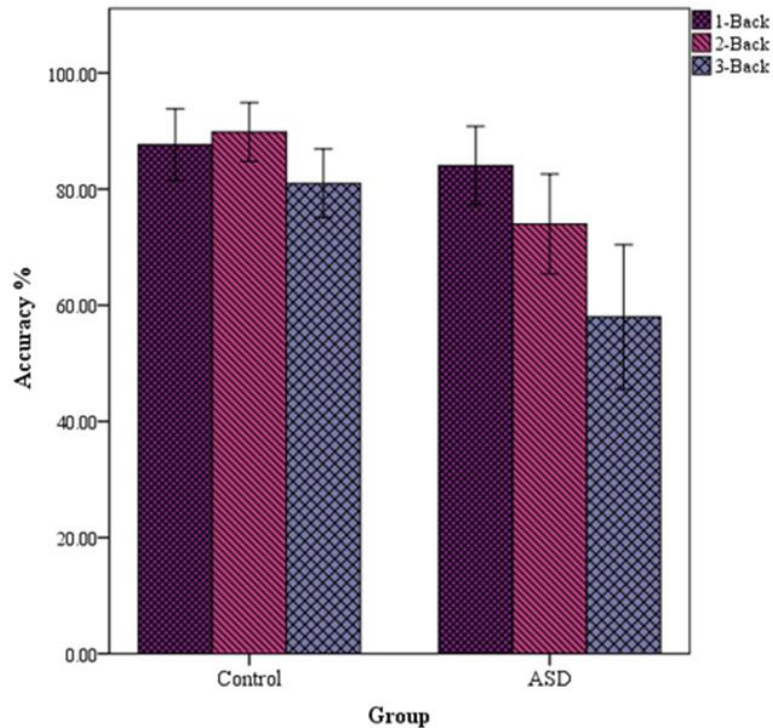
#### 5.3.4.3 Working memory

To further test hypothesis H3, a 3 (N-Back block type: ‘1-back’, ‘2-back’, and ‘3-back’) x 2 (Group: ASD and Control) mixed-model ANCOVA was conducted on accuracy data, with age entered as the covariate. Mean percentage of accuracy were calculated for each group (see Figure 5.10). There was no main effect of Block-Type

(Greenhouse-Geisser corrected  $F(1.70, 63.06) = 1.28, p = .284$ , observed power = .25). However, there was a marginally significant main effect of group ( $F(1, 37) = 4.01, p = .052, \eta^2 = .10$ , observed power = .50), such that the ASD participants were less accurate overall compared to neurotypical controls. Importantly, the main effect of group became statistically significant following the removal of an outlier from the non-ASD group ( $F(1, 36) = 5.60, p = .023, \eta^2 = .14$ , observed power = .63). There was also a significant interaction between Block-Type and Group ( $F(2, 74) = 3.76, p = .035, \eta^2 = .09$ , observed power = .62). This suggests that accuracy scores on 1-, 2-, and 3-back conditions differed for ASD and Control participants.

To investigate this interaction, ANCOVAs were conducted separately for ASD and non-ASD participants on accuracy data. For non-ASD participants, it was found that percentage of accuracy was lower for the 3-back than the 2-back (mean difference = 8.83,  $p = .002$ ) and 1-back (mean difference = 6.67,  $p = .046$ ) conditions. However, the later comparison approached but did not reach statistical significance following the removal of an outlier (mean difference = 6.67,  $p = .058$ ). The remaining comparison between the 1- and 2-back conditions was non-significant (mean difference = .217,  $p = .439$ ). For the ASD group, accuracy scores on the 3-back condition were lower than in the 1-back (mean difference = 26.04,  $p < .001$ ) and 2-back (mean difference = 16.00,  $p = .001$ ) conditions. Accuracy scores were also found to be lower on the 2-back relative to the 1-back condition (mean difference = 10.04,  $p = .032$ ). These findings suggest that although both groups demonstrate performance deficits with increasing cognitive load, this effect is more robust in participants with ASD relative to non-ASD controls. The covariate, age, revealed no significant effect in the model ( $F(1, 37) = 1.51, p = .226$ , observed power = .22). Last, removal of the outlier revealed no further changes in the model.

Power analysis conducted using G\*Power (version 3.0; Faul et al., 2007) indicated that a minimum sample of 66 participants is necessary to detect the smallest effect reported in the current chapter (power = .95, alpha = .05). As such, group difference which failed to reach statistical significance may reflect the study being underpowered



**Figure 5.10 Mean percentage of accuracy for ASD and Control participants as a function of increasing cognitive load.**

Error bars represent standard errors.

#### 5.3.4. Associations between ADOS scores and task performance

Table 5.4 presents the correlations between ADOS scores, dual assessment paradigms, and neutral measures of executive control. Preliminary analyses indicated a significant association between IQ and the ADOS Social Interaction scores. Therefore, two sets of analyses were conducted. First, bivariate correlation coefficients were conducted between ADOS Communication, ADOS Total, dual assessment paradigms, and neutral executive function tasks. Next, partial correlation coefficients (controlling for IQ) were conducted between all behavioural measures and ADOS Social Interaction scores.

Analysis revealed a significant positive association between ADOS Social Interaction scores and overall errors in taking a different perspective, as well as taking a different perspective under high and low cognitive load. To further examine the latter associations, a Steiger's Z-test was conducted on the partial correlations between ADOS Social Interaction scores and different perspective trials performed under high

and low cognitive load (controlling for IQ). This test was non-significant ( $Z=1.05$ ,  $p>.05$ ), suggesting that the partial correlations for different perspective trials performed under low cognitive load were not significantly stronger than that for different perspective trials performed under high cognitive load.

Of note, the association between ADOS Social Interaction scores and errors in taking a different perspective under high and low cognitive load remained significant once two outliers (identified as being 2.5 SDs away from the mean) were eliminated from the analyses. However, the partial correlation between ADOS Social Interaction scores and overall errors in taking a different perspective approached, but did not reach the threshold for statistical significance. Once again, to further examine these associations, a Steiger's  $Z$ -test was conducted on the partial correlations between ADOS Social Interaction scores and different perspective trials performed under high and low cognitive load (controlling for IQ). This test was again non-significant ( $Z=1.72$ ,  $p>.05$ ), suggesting that the partial correlations for different perspective trials performed under high cognitive load were not significantly stronger than that for different perspective trials performed under low cognitive load. A positive association between Total ADOS scores and errors in adopting different perspectives under low cognitive load were also found. None of the remaining correlations between ADOS scores and DTWM performance reached significance levels.

With respect to the Emotional Face Go/No-Go, false alarm rates to sad 'Go' expressions were inversely related to total ADOS scores. The positive association between false alarms to fearful 'Go' expressions and ADOS communication scores was also marginally significant. No other significant associations between and ADOS scores and false alarm rates to emotional 'Go' stimuli were found. However, ADOS Social Interaction scores and false alarm rates to Sad and Fearful 'Go' expressions indicated a trend towards significance. Furthermore, analysis revealed non-significant associations between ADOS scores and false alarm rates across all emotional 'No-Go' stimuli. Last, no statistically significant associations were found between ADOS scores and performance on neutral measures of executive control. However, the negative association between ADOS Social Interaction Scores and WCST performance suggested a trend towards significance. Taken together, these findings yield partial support for hypotheses H5 and H6.



**Table 5-4 Associations between autism severity and behavioural performance**

	ADOS social interaction <sup>† ‡</sup>	ADOS communication	ADOS Total score
<b>Director Task: Director Present</b>			
<i>Error Rates (%)</i>			
Same Perspective	.208 <i>p</i> = .393	-.129 <i>p</i> = .588	.039 <i>p</i> = .870
Different Perspective	.570 <i>p</i> = .011	.171 <i>p</i> = .472	.484 <i>p</i> = .031
	.454 <sup>‡</sup> <i>p</i> = .067		
Same Perspective Low Load	.336 <i>p</i> = .159	.066 <i>p</i> = .782	.299 <i>p</i> = .200
Same Perspective High Load	-.016 <i>p</i> = .948	-.152 <i>p</i> = .522	-.105 <i>p</i> = .659
Different Perspective Low Load	.642 <i>p</i> = .003	.252 <i>p</i> = .284	.572 <i>p</i> = .008
	.483 <sup>‡</sup> <i>p</i> = .050		
Different Perspective High Load	.480 <i>p</i> = .038	.047 <i>p</i> = .845	.348 <i>p</i> = .132
	.509 <sup>‡</sup> <i>p</i> = .037		
<i>Reaction Times (ms)</i>			
Same Perspective	-.112 <i>p</i> = .679	.238 <i>p</i> = .358	.196 <i>p</i> = .451
Different Perspective	-.193 <i>p</i> = .474	.342 <i>p</i> = .179	.267 <i>p</i> = .299
Same Perspective Low Load	-.080 <i>p</i> = .770	.204 <i>p</i> = .433	.172 <i>p</i> = .508
Same Perspective High Load	-.138 <i>p</i> = .609	.114 <i>p</i> = .664	.075 <i>p</i> = .774
Different Perspective Low Load	-.233 <i>p</i> = .385	.222 <i>p</i> = .391	.153 <i>p</i> = .558
Different Perspective High Load	-.118 <i>p</i> = .662	.392 <i>p</i> = .119	.325 <i>p</i> = .203
<b>Emotional Face Go/No-Go</b>			
<i>Total False Alarm Rate to Emotion as 'No-Go'</i>			
Happy Faces	.317 <i>p</i> = .187	.112 <i>p</i> = .637	.195 <i>p</i> = .411
Sad Faces	.000 <i>p</i> = .999	.009 <i>p</i> = .971	-.039 <i>p</i> = .869
Angry Faces	-.238 <i>p</i> = .326	-.011 <i>p</i> = .962	-.140 <i>p</i> = .557
Fearful Faces	.215 <i>p</i> = .377	.037 <i>p</i> = .878	.198 <i>p</i> = .403

Table 5.4 Continued

	<b>ADOS social interaction†</b>	<b>ADOS communication</b>	<b>ADOS Total score</b>
<i>Total False Alarm Rate to Emotion as 'Go'</i>			
Happy Faces	-.066 <i>p</i> = .787	.233 <i>p</i> = .323	.281 <i>p</i> = .231
Sad Faces	-.406 <i>p</i> = .085	-.381 <i>p</i> = .097	.519 <i>p</i> = .019
Angry Faces	-.258 <i>p</i> = .286	.162 <i>p</i> = .495	.084 <i>p</i> = .726
Fearful Faces	-.419 <i>p</i> = .075	.435 <i>p</i> = .055	.235 <i>p</i> = .319
<b>Neutral Executive Function Tasks</b>			
<i>Wisconsin Card Sort Test</i>	-.404 <i>p</i> = .086	.054 <i>p</i> = .821	.176 <i>p</i> = .459
<i>Go/No-Go</i>	-.204 <i>p</i> = .403	.095 <i>p</i> = .691	-.003 <i>p</i> = .991
<i>N-Back Load</i>			
1-Back	-.251 <i>p</i> = .300	-.156 <i>p</i> = .513	-.237 <i>p</i> = .314
2-Back	-.122 <i>p</i> = .620	-.183 <i>p</i> = .439	-.205 <i>p</i> = .385
3-Back	.178 <i>p</i> = .467	.154 <i>p</i> = .518	.195 <i>p</i> = .411

Note. †Partial correlation coefficients presented. ‡Partial and Bivariate correlations without outliers.

## 5.4. Discussion

A large body of research points to ASD-related deficits in social and executive processing. However, given that these studies have predominantly focused on examining social and non-social domains separately, their potential interaction remains relatively underexplored, and we know very little about how individuals with ASD process socially relevant information in the context of executive control.

The present study addressed this gap in the literature by administering concurrent measures of social and executive processing to a sample of adults with and without high-functioning ASD. This study also determined whether impairments on combined paradigms were more pronounced relative to neutral measures of executive control, and whether performance on combined and neutral paradigms were related to diagnostic severity. Based on existing literature, it was predicted that in comparison to typically developing controls, adults with high-functioning ASD would demonstrate poorer performance on measures assessing social cognition and executive control concurrently. In addition, the ASD group were predicted to evidence markedly poorer performance on neutral measures of executive function, but impairments on these measures were expected to be less pronounced relative to impairments on combined paradigms. In terms of task performance and diagnostic severity, it was predicted that poorer performance on combined measures would be related to greater symptom severity across the ADOS-2 domains of communication and social interaction, as well as total scores. Last, significant associations between neutral measures of executive control and autism severity were also predicted, but these associations were expected to be less pronounced relative to those established with combined paradigms.

### 5.4.1. *Perspective-Taking under Cognitive Load*

Consistent with hypotheses H1a and H1b, high-functioning adults with ASD demonstrated significantly poorer performance on the working memory variant of the Director Task. Analysis showed that compared to typically developing controls, individuals with ASD were less accurate in interpreting social cues, particularly when the social task involved representing another person's viewpoint.

Reaction time data revealed a similar pattern of results. Findings showed that compared to IQ and gender-matched controls, individuals with ASD were considerably slower in correctly taking a different perspective. Of note, this finding was more pronounced when different perspective trials were performed under high levels of cognitive load, suggesting that whilst individuals with ASD are generally less adept at shifting perspectives and inhibiting egocentric bias, these difficulties are further exacerbated under increased levels of manipulation.

It is worth noting that both groups evidenced slower responses to same and different perspective trials under high load manipulation, and that individuals with ASD were overall slower in accurately processing social cues. However, the fact that greater performance deficits were incurred on high-load trials requiring perspective-taking indicates that whilst individuals with ASD experience difficulties in processing social information more generally, they are particularly vulnerable to the effects of increased cognitive load whilst representing another person's viewpoint.

This is the first study to report ASD-related impairments on a referential communication task performed under varying levels of cognitive load. Whilst previous studies have utilised variants of this paradigm in their assessment of social reasoning in ASD (e.g., Beeger et al., 2010; Santiesteban et al., 2015), they may have fallen short of adequately tapping the intricate nature of everyday social behaviour and, as a consequence, failed to detect the interpersonal difficulties associated with autism.

As previously discussed, successful navigation of our interpersonal environment is contingent upon the rapid and accurate processing of social input and the ability to use this information to generate adaptive social behaviour. Consequently, errors, or even subtle delays in processing social information is likely to hinder communicative performance and give rise to negative social outcomes (e.g., inappropriate responses to others emotional states). In addition to performing these social computations, real-world interactions are further complicated by the need to concurrently keep track of other, non-social data (e.g., in work and educational settings). As a result, capturing the complex and multifaceted nature of social behaviour within a laboratory environment presents considerable challenges for researchers. Nonetheless, by assessing the interaction between social cognition and executive control under varying levels of cognitive load, the working memory variant of the Director Task provides a closer approximation of the intricacies involved in everyday social interactions and presents a fruitful approach to studying social reasoning in ASD. Indeed, unlike previous versions

of the Director Task, the increased complexity of this variant has proven sensitive to ASD-related impairments in a clinical sample and provides valuable insight into the communicative difficulties experienced in real-world settings.

Taken together, the present study contradicts previous reports of spared perspective-taking abilities in ASD (Beeger et al., 2010; Santiesteban et al., 2015). Furthermore, these data also challenge the suggestion that rather than indexing mentalising, the Director paradigm provides a test of submentalising processes, i.e., domain-general cognitive functions that simulate the effects of mental-state reasoning in social settings (Heyes, 2014; Santiesteban et al., 2015). According to a series of recent papers (e.g., Heyes, 2014; Santiesteban, Catmur, Hopkins, Bird, & Heyes, 2014; Santiesteban et al., 2015) successful performance on measures of social cognition is driven by domain-general processes, without necessarily engaging any complex social functions that require mental-state reasoning. This appears unlikely in view of the current findings suggesting that the Director Present condition requires one to represent another person's viewpoint. Therefore, in contrast to this dichotomous view of social and domain-general cognition, the findings from this chapter suggest that intricate social functions like mentalising require generic processes in order facilitate optimal performance. In other words, whilst these domain-general mechanisms play a critical role in successful communication, they do so by facilitating complex social computations, rather than bypassing them. This interpretation converges with previous work (Apperly et al., 2006; Apperly et al., 2008; Bull et al., 2008), suggesting that ToM use is largely contingent upon the cognitive resources available for executive processing. Nevertheless, similar to Santiesteban et al., (2015), future examinations of mentalising will undoubtedly benefit from incorporating the submentalising hypothesis into their research designs. This line of inquiry will provide a more comprehensive examination of the neurocognitive processes underpinning task performance, and help shed further light on communicative performance in typical and atypical development.

#### *5.4.2. Behavioural Control in the Presence of Affective Information*

In line with previous reports (Tottenham et al., 2011; Yerys et al., 2013), findings showed that False alarm errors were greater when emotional faces were the 'no-go' stimuli relative to when they were the 'go' stimuli (neutral 'no-go'). Furthermore, false alarm errors to emotional 'no-go' faces did not vary based on the valence of

expressions. This result suggests that affective information of positive and negative valence is equally distracting when regulating impulsive responses, relative to neutral information. With respect to emotion, false alarm rates were significantly higher for sad faces, followed by angry faces, with the fewest errors made to fearful and happy faces. Poorer performance on sad trials have been documented in previous investigations (Tottenham et al., 2011; Yerys et al., 2013), and may partly arise from the greater perceptual similarity between sad and neutral faces (Tottenham et al., 2011). Indeed, some basic emotions are more distinct than others and may present reduced interference effects in the context of executive processing.

There were no group differences in overall false alarm rates, and performance deficits on emotional ‘no-go’ trials was evident across all participants. However, there was a trend (which became significant following the removal of an outlier) towards the ASD group incurring higher false alarm errors to emotional ‘no-go’ stimuli, relative to neutral distractors. This finding suggests that inhibiting pre-potent responses in the presence of socio-affective information is particularly difficult for individuals with ASD. Nevertheless, given the small sample size, this interpretation requires further investigation in a larger group of adults with high-functioning ASD.

Taken together, these findings contradict Geurts et al’s (2009) report of intact behavioural inhibition in the presence of affective information and, instead, converge with Yerys et al’s findings demonstrating ASD-related impairments. Importantly, the current study extends these findings to high-functioning adults with ASD and suggests that autism-related difficulties in processing affective information in the context of executive control may persist into adulthood. However, along with a larger sample size, future investigations should make use of longitudinal designs in order to provide a more comprehensive assessment of this interpretation.

Whilst these data appears consistent with Yerys et al., (2013), unlike their investigation, the present study is unable to determine whether performance on this paradigm was influenced by co-occurring symptoms of attention deficit hyperactivity disorder (ADHD). Yerys and colleagues reported a positive association between ADHD symptomatology and impulsive responses to emotional and neutral No-Go stimuli, but found no significant associations between task performance and scores on the ADOS domain of Social+Communication. The authors conclude that the higher false alarm errors evidenced by autistic children is attributable to co-occurring ADHD symptoms. Although the current study provides an examination of the link between

ASD symptomatology and response inhibition to affective information (discussed later in this section), a future priority is to examine independent contributions of autism and ADHD symptomatology in adults with high-functioning ASD.

Future investigations employing this paradigm should also include an emotion recognition task in order to determine whether participants differ in their ability to identify affective expressions. Whilst the main effect of emotion suggests that false alarm errors to emotions were comparable across ASD and non-ASD participants, matching groups based on basic emotion recognition abilities will provide a more detailed picture on how affective information impacts executive control. In addition, the ecological validity of this task could be further enhanced through the inclusion of more subtle expressions of basic emotions, as well as more complex social emotions (i.e., embarrassment, pride, guilt etc.). As discussed in Chapter 4, the Emotional Go/No-Go in its current form consists of extreme expressions of facial affect. However, given that real-world interactions involve a wider range of emotions depicted at varying levels of intensity, incorporating these elements will help increase sensitivity to ASD-related difficulties and provide a closer approximation of social interactions in everyday contexts.

#### *5.4.3. Executive Processing in the Absence of Socio-Affective Information*

The study reported in this chapter also examined whether individuals with ASD were impaired on neutral measures of executive control. In line with our predictions, individuals with ASD evidenced significantly poorer set-shifting ability on the WCST and N-Back, in comparison to typically developing controls. This finding appears consistent with previous literature documenting autism-related impairments in cognitive flexibility (e.g., Austin et al., 2014; Ozonoff & Jensen, 1999; Pellicano et al., 2007; Shu et al., 2001), and working memory (e.g., Corbett et al., 2009; Cui et al., 2010; Goldberg et al., 2005; Happé et al., 2006; Landa & Goldberg, 2005; Luna et al., 2007; Williams et al. 2006), suggesting that individuals with ASD are less adept at adjusting their behaviour in line with changing contingencies and experience greater difficulties in actively monitoring and updating incoming information. Of note, whilst ASD participants demonstrated poorer performance on the WCST, N-Back, and DTWM, the greater magnitude of impairments on the combined paradigm suggests that deficits in cognitive flexibility and working memory are potentially exacerbated in the presence of socially-relevant stimuli. This interpretation complements the notion that

generic cognitive processes play a vital role in the processing of socio-affective information, and in the generation of optimal social responses.

In contrast, however, performance on the neutral Go/No-Go task was comparable across both groups. Whilst this finding contradicts previous reports of impaired response inhibition in those with clinical (Christ et al., 2007) and subclinical (Chapter 3) ASD, it accords with studies indicating spared abilities in this domain of executive control (e.g., Ozonoff et al., 1994; Schmitz et al., 2006). This finding, combined with the trend towards ASD participants exhibiting poorer behavioural control on emotional ‘no-go’ trials, suggests that difficulties in regulating impulsive responses in ASD may only arise in the presence of affective information. However, as highlighted above, this interpretation requires further investigation in a larger sample of ASD adults.

#### *5.4.4. Associations between Autism Severity and Behavioural Performance*

Consistent with H5, findings revealed significant associations between autism severity and concurrent measures of social and executive processing. Results showed that ASD adults with higher scores on the ADOS domain of Social Interaction experienced significantly greater difficulties in adopting another person’s viewpoint on a referential communication task. Of note, these difficulties were independent of general cognitive ability and evident under both high and low levels of cognitive load. Furthermore, the correlation between ADOS Social Interaction scores and different perspective trials performed under high and low levels of cognitive load remained significant following the removal of two outliers. Total ADOS scores were also related to impairments in perspective-taking, but this association emerged only on overall scores and low cognitive load trials. In contrast, however, no statistically significant associations were found between the ADOS Communication scale and performance on the working memory variant of the Director Task. Whilst this finding is somewhat surprising given previous reports of an overlap between communication scores and performance on independent measures of ToM and executive control (Joseph & Tager-Flusberg, 2004; Tager-Flusberg, 2003), it suggests that online usage of ToM is primarily associated with skills pertaining to social reciprocity. Future studies applying the DTWM variant to younger ASD populations will help identify whether this relationship is present among younger individuals, or restricted to autistic adults.



Together, these data appear consistent with previous reports documenting a meaningful overlap between autism severity and performance on measures examining ToM and executive control (Joseph & Tager-Flusberg, 2004; Tager-Flusberg, 2003). The present study further extends these findings to include a referential communication task performed under varying levels of cognitive load, demonstrating that impairments on a dual-assessment paradigm map onto symptom severity among adults with high-functioning ASD. However, due to employing a brief measure of general cognitive ability, the present study is unable to identify the potential contribution of language to the relationship established between DTWM performance and ADOS scores. As highlighted earlier in this chapter (section 5.1.2), studies examining the link between ToM ability, executive function, and symptom severity in younger populations have revealed a significant contribution by language competence (Joseph & Tager-Flusberg, 2004; Tager-Flusberg, 2003). Future research incorporating more comprehensive measures of verbal IQ is therefore necessary to further our understanding of the link between diagnostic severity and performance on concurrent measures of ToM and executive control in adult populations.

With regards to the Emotional Go/No-Go paradigm, findings showed that individuals with higher ADOS total scores made fewer commission errors on trials where sad expressions were the ‘Go’ stimuli. Whilst this association is somewhat unexpected, the low false alarm rate may be consequence of higher errors of omission i.e., failing to respond to the target expressions. In other words, rather than demonstrating enhanced inhibitory control in the presence of sad ‘Go’ stimuli, ASD individuals with greater symptom severity may have evidenced reduced responses across these particular trials. This interpretation appears consistent with previous work documenting ASD-related difficulties in sadness recognition (e.g., Ashwin et al., 2006; Wallace et al, 2011). However, this explanation is challenged by the absence of a statistically significant negative correlation between total ADOS symptomatology and commission errors on sad ‘No-Go’ trials, as well as the marginally significant positive association between ADOS Communication scores and commission errors on Fear ‘Go’ trials. Consequently, these findings demonstrate the need for a more comprehensive examination of response inhibition to affective stimuli among those with ASD. Future investigations employing the Emotional Go/No-Go paradigm would therefore benefit from including an index of omission errors as well as false alarm rates. In addition, whilst the task stimuli consists of facial expressions presented at full

intensity only, matching ASD participants based on emotion recognition abilities will help provide a more accurate assessment of the link between diagnostic severity and affective information processing in the context of executive control.

In line with Yerys et al., (2013), findings revealed non-significant correlations between autism severity and false alarm rate to emotional ‘No-Go’ stimuli. This finding suggests that difficulties in regulating impulsive responses to affective stimuli in ASD populations may be a consequence of co-morbid ADHD, rather than autism per se. However, as highlighted earlier in the discussion, the present study is unable to identify the exact contribution of ADHD symptoms to performance on the Emotional Go/No-Go. Thus, along with language ability, future investigations on the link between autism severity and dual assessment paradigms should also examine the influence of comorbid ADHD symptoms. This line of inquiry may help elucidate the overlapping and distinct endophenotypes for ASD and ADHD.

In contrast to concurrent measures of social and executive processing, no statistically significant associations between neutral measures of executive control and autism severity were found. These findings contradict previous behavioural work documenting significant associations between communicative symptoms and impaired executive processing in younger populations (e.g., Joseph & Tager-Flusberg, 2004). Importantly, however, the present data suggests that whilst neutral measures of executive control lack sufficient explanatory power to detect autism severity in adults with ASD, more complex and ecologically valid dual assessment paradigms, such as the working memory variant of the Director Task, do. Indeed, it is worth noting that the small sample size ( $n = 20$ ) is likely to have reduced sensitivity to moderate or small associations between ASD symptomatology and the key variables of interest. Thus, in view of the limited sample size, rather than suggesting that neutral measures are simply unrelated to ADOS domains in adult populations, the most reasonable conclusion to draw from these data is that referential communication skills have a stronger association with diagnostic severity than classic measures of executive control.

#### *5.4.5. Limitations and Future Directions*

Some limitations of this research should be noted. Due to time constraints in recruitment and testing, as well as the difficulties inherent in recruiting participants with low-prevalence conditions, analyses were restricted to a relatively small sample

size and matching clinical and comparison samples based on chronological age was not possible. In addition, the low power observed in the present study may have reduced sensitivity to other important effects. Future research should therefore aim to replicate these exploratory findings in larger samples that are closely matched on the key demographic variable of age. Specifically, power analysis indicated that a minimum of 33 participants per group is necessary to detect smaller effects.

Moderate deviations to normal distribution observed in the ASD and control groups may have also had an impact on the results. Nonetheless, emphasis in future replications should be placed on increasing participant numbers rather than striving to attain better distribution of data.

A further limitation is the lack of control over co-morbid conditions, such as ADHD. Autism and ADHD often co-occur, giving rise to more a complex neurocognitive profile. Indeed, as highlighted above, there is some evidence to suggest that ASD and ADHD symptomatology differentially impact performance on the Emotional Go/No-Go paradigm. Nevertheless, given the challenging nature clinical recruitment, we were unable to account for the ‘additive’ impact of other, co-occurring conditions. Consequently, the potential influence of comorbid disorders on task performance makes it difficult to tease apart the “pure” effects of ASD.

## **5.5. Conclusion**

Findings from the present study demonstrates ASD-related deficits on a referential communication task performed under varying levels of cognitive load. Specifically, findings showed that whilst ASD adults were poorer at processing social information more generally, this effect was most pronounced on different perspective trials performed under high cognitive load. ASD participants were also found to be less adept in regulating behavioural responses in the presence of affective information, and evidenced poorer performance on certain measures of neutral executive function. The magnitude of impairments on the DTWM appeared to be greater relative to neutral measures of executive control, suggesting that the presence of socially-relevant stimuli may serve exacerbate executive impairments. With regards to symptom severity, analysis revealed significant associations between ADOS scores and impaired

perspective-taking abilities on the DTWM. In contrast, no statistically significant associations were found between the ADOS and neutral measures of executive control, demonstrating the referential communication task as a more sensitive index of social impairments in ASD.

This is the first study of its kind to report impaired performance on concurrent measures of social and executive processing in a sample of high-functioning adults with ASD. It is also the first study to provide evidence of significant relationship between Director Task performance and impaired social functioning among ASD participants with greater symptom severity.

The next and final chapter of this thesis will summarise the findings from the present and previous empirical chapters, and will discuss their implications.

## **6 General Discussion**

## 6.1. Overview

Humans are inherently social creatures and a key function of our cognitive toolkit is to facilitate the successful navigation of varying and complex social situations. This requires processing a constant stream of socially relevant cues from multiple modalities, and using this information to generate adaptive and goal-directed behaviour. Performing these social computations successfully is contingent upon a number of complex abilities (e.g., maintaining attention, alternating between our own and others' perspectives, inhibit inappropriate behaviours; Thornton & Conway, 2013; Ybarra & Winkielman, 2012), suggesting that along with social cognition, other higher-order mechanisms, such as executive control, may be essential to optimal social performance.

There is a growing body of evidence to suggest that the prefrontal regions supporting social and executive processes follow a prolonged developmental trajectory that extends into the third decade of life. Of note, disruptions in these higher-order abilities have been purported to play a vital role in the social deficits characterising ASD. Although the past few decades have witnessed a considerable surge of interest in these processes, a number of areas require additional research attention.

Although most studies examining social and executive processes indicate a protracted developmental course of maturation, these investigations have mainly primarily focused on younger adolescents, meaning that limited attention has been paid to the age-related changes in higher-order abilities between middle adolescence and young adulthood. In addition, autism research to date has primarily taken a dichotomous approach to the study of social cognition and executive control. Whilst relevant investigations highlight a meaningful overlap between social and non-social processes, examining these domains in isolation provides limited insight into how socio-affective information is processed in the context of executive control.

There is also an emerging body of research suggesting that typically developing individuals with higher levels of autism-like traits may be more prone than the general population to ASD-related difficulties. At present, however, research profiling social and executive processing at the subclinical level remains considerably limited, and we still know very little about whether ASD traits are associated with variability in

processing of socio-affective information in the context of executive control. The current thesis set out to advance knowledge in the above areas using behavioural data drawn from typically developing adults and adolescents, as well as a sample of high-functioning adults with ASD.

## **6.2. Research questions addressed in this thesis**

The studies presented in this thesis sought to address to five outstanding research questions: 1) Are there age-related improvements in higher-order cognition between middle adolescence and young adulthood? 2) Do typically developing individuals with elevated levels of autism traits display a similar pattern of difficulties in social cognition and executive control to those with a clinical diagnosis of ASD, and could socio-affective difficulties be attributed to trait alexithymia? 3) Are elevated levels of autism symptomatology associated with poorer performance on concurrent measures of social and executive processing? 4) Do high-functioning adults with ASD experience difficulties in processing socially-relevant cues in the context of executive control, and are these deficits more pronounced relative to neutral measures of executive function? and, finally, 5) Does task performance on combined paradigms relate to diagnostic severity of ASD, and are these associations stronger when compared to neutral measures of executive control? The findings in relation to each of these questions will be considered in the section below.

### *6.2.1. Are there age-related improvements in higher-order cognition between middle adolescence and young adulthood?*

**Chapter 2** described a two-part behavioural study where an extensive battery of measures were employed to compare the social and executive function profiles of typically developing mid-adolescents (16-17 years) and young adults (19-22 years). Overall, findings showed that many aspects of higher-order cognition, such as facial affect processing, theory of mind, and executive function, undergo a period of marked development between middle adolescence and the early stages of adulthood. These results therefore appear consistent with neurophysiological data showing a prolonged

course of maturation for the frontal networks underpinning social and executive processing.

Firstly, findings showed that in comparison to young adults, adolescents were less adept at identifying basic emotions of negative valence. These data contradict previous reports of facial affect recognition stabilising around 15 years of age (McGivern et al., 2002), and, instead, corroborate Thomas et al's, (2007) results demonstrating marked improvements in affect processing between adolescence and adulthood. Importantly, our findings extend Thomas and colleagues results by showing increased difficulties in the recognition of all negative emotions for adolescents relative to young adults. Adolescents were also poorer at identifying expressions of happiness, although this finding was at trend level. Consequently, these results provide evidence that facial affect processing continues to advance between the mid-to-later stages of adolescence and early adulthood. These data also fit in with neurophysiological research demonstrating a prolonged course of development for the frontal circuitry supporting facial affect recognition. As mentioned previously, numerous studies indicate rapid maturation of the frontal regions during adolescence (Casey et al., 2000; Giedd et al., 1999; Spear, 2000), with considerable changes occurring well into the third decade of life (Giedd et al., 2004). Therefore, the advanced emotion processing skills displayed by young adults potentially reflect a more refined and efficient neural system supporting the recognition of facial affect.

It is also worth noting that findings revealed marked differences in facial affect processing over a relatively short period of development. For example, whilst Thomas et al., recruited a broader range of adults (aged 25-50), our study focused on a much younger group (aged 19-22) to identify whether significant changes in the ability to read facial expressions occurred between middle adolescence and the early stages of adulthood. Therefore, our data suggest that facial affect processing continues to develop beyond adolescence and may reach adult levels of maturity between 19 and 22 years of age. To confirm this result, future investigations would need to include a third sample comprising an older group of adults in order to confirm this result.

Second, findings revealed evidence of age-related improvements in mentalising ability between middle adolescence and early adulthood. Findings showed that in comparison to adults, adolescents experienced greater difficulties in attributing mental states to static and naturalistic stimuli.



This finding goes against recent reports suggesting stabilised mental state reasoning between the mid-to-later stages of adolescence (Bosco et al., 2014; Taylor et al., 2013), and, instead, appears consistent with behavioural work (Dumontheil et al., 2010) documenting continued ToM development between the later stages of adolescence and adulthood. Whilst we are unable to determine the underpinnings of this late developmental trajectory, our findings appear consistent with neuroimaging research demonstrating that the neural architecture supporting ToM ability undergoes profound structural (e.g., Giedd et al., 1999) and functional (e.g., Blakemore, 2008) changes during adolescence.

Conversely, findings revealed no evidence of age-related changes in affective empathy, with adults and adolescents evidencing comparable performance on the self-assessment manikin task. These findings indicate that whilst mentalising ability follows a prolonged course of maturation that extends into the early stages of adulthood, the capacity to resonate with others affective experiences becomes established considerably sooner. Of note, these data yield support for previous reports establishing mental state reasoning and affective resonance as separate forms of empathy, with interacting, yet partially distinct, neural substrates, and diverse developmental trajectories (Decety, 2011; Decety & Michalska, 2010).

Last, findings revealed age-associated improvements across all measures of executive processing between middle adolescence and early adulthood. These data showed that relative to young adults, adolescents evidenced poorer set-shifting efficiency scores on the WCST, higher commission errors on the Go/No-Go, and reduced planning ability on the ToL task. These data converge with previous reports documenting age-related improvements on tasks assessing planning ability (Albert & Steinberg, 2011; De Luca et al., 2003; Guevera et al., 2012; Huizinga et al., 2006; Luciana et al., 2009), set-shifting (Huizinga et al., 2006), and response inhibition (Huizinga et al., 2006; Johnstone et al., 2005; Tamm et al., 2002), and contradict data from previous studies suggesting that certain domains of executive control reach adult-level maturity by middle adolescence (Anderson et al., 2001; Taylor et al., 2013). Once again, these results appear to converge with existing imaging data suggesting that the neural mechanisms underpinning executive abilities follow a protracted developmental trajectory and become progressively more fine-tuned with age (Casey et al., 2000; Giedd et al., 1999; Giedd et al., 2004; Spear, 2000).

Taken together, the findings described in **Chapter 2** provide evidence suggesting that facial affect processing, mental-state reasoning, and executive control continue to advance between mid-to-late adolescence and young adulthood. These data replicate and extend previous research by showing evidence of late-occurring advancements in multiple domains of higher-order cognition, and provide a more comprehensive profile of social and executive function development during the later stages of adolescence.

*6.2.2. Do typically developing individuals with elevated levels of autism traits display a similar pattern of difficulties in social cognition and executive control to those with a clinical diagnosis of ASD, and could difficulties within these domains be attributed to trait alexithymia?*

As previously discussed, recent investigations suggest that social cognition and executive control are interrelated constructs following a prolonged developmental trajectory, and that autism-related difficulties within these domains extend beyond those with a clinical diagnosis of ASD. In contrast to the growing number of studies examining the link between executive processing and social cognition, and in their respective relationships with autism, little relevant research has been conducted at the subclinical level.

**Chapter 3** addressed this gap in the literature by examining the facial affect processing, empathy, executive function, and ASD trait link in a large sample of typically developing adults and adolescents. The battery of tasks employed in Chapter 2 were utilised to examine whether individuals with elevated levels of autism traits displayed a similar profile of difficulties in social and executive processing to those observed in ASDs. A further aim was to determine the potential contribution of alexithymia to performance on measures of social cognition, as well as examining its association with multiple domains of executive control. Overall, findings showed that individuals with elevated levels of ASD traits exhibit a similar profile of difficulties in affect recognition, empathic processing, and executive function to those observed in ASDs. These associations were found independent of trait alexithymia levels.

With regards to affect recognition, findings showed that individuals with higher levels of ASD traits were poorer in identifying facial expressions of sadness. This association was not explained by co-occurring alexithymia. This result appears

consistent with previous reports documenting atypical sadness recognition in ASD (Ashwin et al., 2006; Ellis & Leafhead, 1996), and speaks against those reporting intact affect processing (Adolphs et al., 2001; Castelli, 2005; Tracy et al., 2011). Specifically, the finding that elevated autism traits were associated with impaired sadness recognition over more perceptually distinct emotions (e.g., fear and anger), indicates a qualitatively similar, though less severe pattern of impairments than that observed in ASD. In other words, whilst individuals with higher autism symptomatology experience difficulties in identifying expressions of sadness, unlike those with a clinical diagnosis, their capacity to process other, more distinct negative emotions seems to be intact. Furthermore, the fact that this association was unique to ASD appears to contradict recent work suggesting that comorbid alexithymia may account for the emotional difficulties associated with ASD (Cook et al., 2013). Future research examining emotion identification in relation to subclinical ASD traits would profit from incorporating more complex social emotions (e.g., pride, shame, embarrassment etc.) This line of inquiry would further our understanding of socio-affective processing among those with elevated levels of autism symptomatology.

To date, research examining empathic processing in ASD suggests dissociable deficits, with impaired cognitive and spared affective empathy (Dziobek et al., 2008; Jones et al., 2010; Lockwood et al., 2013; Schwenk et al., 2012). In line with these results, findings showed that performance on both static (RMET) and naturalistic (MASC) measures of ToM was negatively associated with ASD symptomatology. A similar pattern was observed with trait alexithymia. However, neither ASD traits, nor alexithymia were related to the affective domain of empathy. Further analysis revealed unique associations between subclinical autism traits and naturalistic ToM. Specifically, we found that individuals with higher levels of ASD symptomatology and lower intellectual ability experienced greater difficulties in attributing mental states to movie characters in a real-life social context, but not to static images depicting the eye region of the face. Alexithymia and age did not make significant contributions to naturalistic ToM performance within these models.

These data are also consistent with previous reports documenting impaired mindreading abilities in typically developing individuals with elevated levels of ASD traits (Gökçen et al., 2014; Lockwood et al. 2013), and extend their findings to include a naturalistic measure of ToM ability. This finding is of particular importance as it demonstrates that, along with capturing more profound ToM deficits present in those

with a clinical diagnosis (Dziobek et al., 2006; Lahera et al., 2014), the MASC can also detect milder ToM impairments in typically developing populations. Interestingly, our results concerning alexithymia appear to be inconsistent with recent theory and evidence suggesting that alexithymia accounts for the observed empathy deficits related to ASD (Bird & Cook, 2013). Instead, our data converge with Lockwood et al's, (2013) in suggesting that alexithymia cannot explain the mentalising difficulties associated with elevated autism traits.

Significant associations between autism symptomatology and increased difficulties in executive processing were also observed. Individuals with higher ASD traits were characterised by poorer response inhibition and impaired set-shifting ability. In contrast, however, we found no significant association between planning ability and ASD traits. With respect to alexithymia, impairments were only observed on the response inhibition domain of executive processing.

The observed relationships between autism symptomatology, cognitive flexibility, and impaired response inhibition are in line with previous reports from ASD populations (Austin et al, 2014; Pellicano et al, 2007), but do not corroborate difficulties in planning ability (Hill, 2004). Furthermore, whilst our results appear consistent with recent examinations of executive control in subclinical ASD (e.g., Christ et al, 2010; Gökçen et al, 2014) they partly contradict data reported by Christ et al. (2010). This discrepancy may arise from the varied assessment techniques employed. For instance, Christ et al, (2010) utilised a self-report measure of higher-order cognition, whereas the present study employed behavioural assessments of all relevant executive domains, which may have been more sensitive to individual differences in response inhibition. Together, these findings demonstrate that response inhibition and cognitive flexibility are adversely affected in those with elevated autism symptomatology, and suggest that the executive difficulties characterising ASDs extend beyond those with a clinical diagnosis, into the general population.

It is also worth noting that **Chapters 2 and 3** of this thesis demonstrated significant interrelationships between facial affect processing, empathic function, and executive control. Consistent with previous investigations (e.g., Apperly et al., 2006; Dumontheil et al, 2010; Pellicano, 2007), these findings yield further support for the meaningful overlap between social and executive processing.

In addition, findings from Chapter 3 revealed unique associations between executive control and naturalistic ToM. Namely, we found that along with autism traits,

cognitive flexibility was also a key factor in shaping optimal performance on the MASC task. Indeed, the influential role of executive processing does not come as a surprise, given that this measure provides a more complex and ecologically valid index of mental-state reasoning. Hence, these findings suggest that successful performance on the MASC draws upon key neurocognitive processes enabling flexible adaptation to altering social demands, and the ability to adopt different perspectives during mental state reasoning.

Overall, findings from Chapter 3 provide a deeper understanding of social and executive processing in subclinical ASD. These data show that individuals with elevated levels of autism traits display a qualitatively similar, though less severe, profile of difficulties in social cognition and executive control as their ASD counterparts. The findings also suggest that deficits within these domains are unique to ASD and are not explained by co-occurring alexithymia.

### *6.2.3. Are elevated levels of autism symptomatology associated with poorer performance on concurrent measures of social and executive processing?*

**Chapter 4** examined whether subclinical autism traits were associated with difficulties in processing social information in the context of executive control. A second aim was to determine the potential influence of alexithymia on concurrent measures of social and executive processing.

Findings showed that typically developing individuals with elevated autism traits displayed poorer performance on a referential communication task performed under varying levels of cognitive load. Specifically, participants with higher ASD traits were slower in accurately adopting different perspectives whilst under low manipulation. In contrast, however, there was no significant association between ASD traits and slowed performance on different perspective trials performed under high levels of cognitive load. In light of the small sample size and relatively modest correlation coefficient, this should be considered a preliminary finding that requires further investigation. Although the positive association between autism symptomatology and slowed RTs to different perspective trials performed under cognitive load is somewhat surprising, it may indicate a pattern of impairments unique to subclinical levels of ASD. It is quite possible that these preliminary findings point towards a pattern of impairments specific to subclinical levels of autism traits. They suggest that whilst there may be a generic

negative impact of high load on perspective-taking abilities, difficulties in processing information about another person's viewpoint under low cognitive load may be exclusive to typically developing individuals with elevated levels of autism traits.

With respect to the Emotional Go/No-Go, there was no evidence of elevated ASD traits being associated with poorer response inhibition in the presence of affective stimuli. Given previous reports documenting autism-related deficits on this measure (Yerys et al., 2013), our findings suggest that difficulties in regulating behavioural responses to affective information may be restricted to clinical populations with a diagnosis of ASD. However, it is worth noting that in the study described in Chapter 3, findings revealed evidence of impaired affect processing and response inhibition among those with elevated levels of ASD traits. Therefore, an alternative account for this discrepancy may be that the Emotional Go/No-Go task in its current form is unable to detect more subtle impairments in subclinical populations. To address this issue, future investigations will need to adapt this measure by reducing stimuli presentation times and incorporating more complex and subtle expressions of affective states. Such modifications will serve to increase task sensitivity and help determine whether regulating behavioural responses in the presence of affective information is indeed spared among those with subclinical autism traits.

Last, whilst findings indicated a trend towards poorer behavioural regulation to emotional 'no-go' faces, there were no statistically significant associations between trait alexithymia and the working memory variant of the Director Task. Consequently, this result indicates that difficulties in perspective-taking under cognitive load are unique to autism symptomatology.

*6.2.4. Do high-functioning adults with ASD experience difficulties in processing socially-relevant cues in the context of executive control, and are these deficits more pronounced relative to neutral measures of executive function?*

**Chapter 5** extended the dual assessment paradigms reported in Chapter 4 to a sample of high-functioning adults with ASD. A second was to examine whether deficits on these combined measures were more pronounced relative to neutral measures of executive control.

First of all, high-functioning adults with ASD were found to demonstrate significantly poorer performance on the DTWM paradigm. Findings showed that compared to typically developing controls, individuals with ASD were less accurate in interpreting social cues, particularly when the social task required adopting the director's perspective. Findings in relation to reaction times revealed a similar pattern of results, with the ASD group evidencing considerably slower responses to correct different perspective trials. Once again, this finding was more pronounced when different perspective trials were performed under high levels of cognitive load, suggesting that whilst individuals with ASD are generally poorer at shifting perspectives and inhibiting egocentric bias, these impairments appear to be further exacerbated whilst processing social information under high levels of cognitive load.

Findings also revealed slower RTs to correct same and different perspective trials performed under high load manipulation. In addition, the ASD group was overall slower in accurately processing social information. However, the fact that greater performance deficits were evidenced on high-load trials involving perspective-taking abilities suggests that whilst individuals with ASD experience difficulties in processing social cues more generally, they are particularly prone to the impact of increased cognitive load whilst adopting a different perspective.

Overall, these results appear to contradict previous reports demonstrating spared perspective-taking abilities on the DTWM for those with ASD (e.g., Beeger et al, 2010; Santiesteban et al, 2015). One explanation for this discrepancy is the use of a more complex task variant. Therefore, previous investigations may have failed to tap the complex nature of everyday social interactions and, as a consequence, failed to detect the interpersonal difficulties associated with ASD.

Second, findings from the Emotional Go/No-Go paradigm revealed no significant group differences in overall false alarm rates, and performance deficits on emotional 'no-go' trials was evident across all participants. However, there was a trend towards the ASD group incurring higher false alarm errors to emotional 'no-go' stimuli, in comparison to neutral distractors. This finding suggests that regulating pre-potent responses in the presence of socio-affective information is particularly challenging for individuals with ASD. Nevertheless, given the medium effect size and limited power, this finding warrants further investigation in larger group of adults with high-functioning ASD.

These findings go against previous work demonstrating (Geurts, et al, 2009) intact behavioural inhibition in the presence of affective information and, instead, support Yerys et al's findings demonstrating autism-related deficits in task performance. Of note, the current study extends these findings to high-functioning adults with ASD and suggests that autism-related difficulties in processing affective information in the context of executive control may persist into adulthood. Although longitudinal investigations are necessary in order to provide a more comprehensive assessment of this interpretation.

However, as discussed in Chapter 5, unlike Yerys et al's, (2013) investigation, this study was unable to determine whether performance on this Emotional Go/No-Go paradigm was influenced by co-occurring symptoms of attention deficit hyperactivity disorder (ADHD). Yerys et al, (2013) finds a positive association between ADHD symptomatology and impulsive responses to emotional and neutral No-Go stimuli, but found no significant associations between task performance and scores on the ADOS domain of Social+Communication. Based on these findings, the authors conclude that higher false alarm errors evidenced by autistic children are attributable to co-occurring ADHD symptoms. Future research will therefore need to index independent contributions of autism and ADHD symptomatology in adults with high-functioning ASD.

Finally, ASD participants were found to demonstrate difficulties in cognitive flexibility and working memory. This finding appears to converge with previous literature documenting autism-related impairments in cognitive flexibility (e.g., Austin et al., 2014; Ozonoff & Jensen, 1999; Pellicano et al., 2007; Shu et al., 2001) and working memory, suggesting that individuals with ASD are significantly poorer at adjusting their behaviour in line with changing task demands as well as maintain and updating goal-relevant information. Of note, whilst ASD participants demonstrated poorer performance on the WCST, N-back, and DTWM, the greater magnitude of impairments on the combined paradigm suggests deficits in cognitive flexibility and working memory may be exacerbated in the presence of socially-relevant information. This interpretation is consistent with the notion that generic cognitive processes play a vital role in the processing of socio-affective information, and in the generation of optimal social responses.

Findings revealed comparable performance on the neutral Go/No-Go task for both ASD and non-ASD groups. Although this finding fails to corroborate previous reports



of impaired response inhibition in those with clinical (Christ et al., 2007) and subclinical (Chapter 3) ASD, it converges with studies demonstrating spared abilities response inhibition (e.g., Ozonoff et al., 1994; Schmitz et al., 2006). This finding, in conjunction with the trend towards ASD participants demonstrating impaired behavioural control on emotional ‘no-go’ trials, suggests that response inhibition deficits in ASD may only emerge in the presence of affective content. It should be acknowledged, however, that this interpretation requires further investigation in a larger sample of ASD adults.

*6.2.5. Does task performance on combined paradigms relate to diagnostic severity of ASD, and are these associations stronger when compared to neutral measures of executive control?*

The study reported in **Chapter 5** found that ASD adults with greater symptom severity evidenced poorer performance on a referential communication task performed under varying levels of cognitive load. Specifically, findings showed that individuals with more profound impairments in the domain of social interaction were less adept at representing another person’s viewpoint. These associations were independent of general cognitive ability, and evident on both high and low load trials. Total ADOS scores were also related to a higher percentage of perspective-taking errors, with positive associations observed on overall scores as well different perspective trials performed under low cognitive load.

Conversely, there were no significant correlations between communicative scores and perspective-taking ability on the Director Task. Although this result is inconsistent with previous work documenting an overlap between communicative symptoms and performance on independent measures of ToM and executive control (Joseph & Tager-Flusberg, 2004; Tager-Flusberg, 2003), it potentially suggests that mentalising difficulties among ASD adults are more strongly associated with impairments in social reciprocity than with communicative functioning. It should also be noted that this pattern of findings may be a consequence of the limited statistical power afforded by the relatively small sample size. Therefore, future investigations in larger samples could increase sensitivity to moderate or small associations between ADOS scores and

Director Task performance. Such an approach will help provide a more detailed assessment of the link between online ToM use and diagnostic severity.

Overall, these data are in line with previous work reporting significant associations between diagnostic severity and performance on measures assessing ToM and executive control (Joseph & Tager-Flusberg, 2004; Tager-Flusberg, 2003). A novel contribution of the study in Chapter 5 is that it extends these findings to include a referential communication task, demonstrating for the first time that impairments on a dual-assessment paradigm map onto diagnostic severity in adults with ASD. Nonetheless, further studies are needed to help provide a clearer picture of this relationship. In particular, examining these associations in larger samples, as well as accounting for the potential influence of language ability and co-morbid conditions will provide a more comprehensive assessment of the link between referential communication skills and autism severity.

Findings in relation to the Emotional Go/No-Go paradigm were less clear. For example, contrary to predictions, correlational analyses found that individuals with greater symptom severity (Total ADOS scores) evidenced fewer commission errors on sad ‘Go’ trials. One possible explanation for this finding is that difficulties in identifying sad expressions may have led to higher errors of omission. Thus, rather than demonstrating enhanced inhibitory control in the presence of sad ‘Go’ stimuli, autistic adults with greater symptom severity may have failed to respond to these particular trials. Nonetheless, whilst this interpretation converges with previous work documenting autism-related deficits in sadness recognition (e.g., Ashwin et al., 2006; Wallace et al. 2011), it is challenged by the absence of a significant association between symptom severity and reduced false alarms to sad ‘No/Go’ stimuli. Clearly, there is need for a more comprehensive assessment of how diagnostic severity relates to affective information processing in the context of executive control. This could be achieved by assessing omission errors and reaction time data in conjunction with false alarm rates. Matching ASD participants based on emotion recognition abilities will also help provide a more accurate assessment of the link between autism severity and behavioural regulation in responses to affective content.

Findings also revealed non-significant correlations between diagnostic severity and false alarm rates to emotional ‘No-Go’ stimuli. This result is consistent with Yerys et al. (2013) and suggests that deficits in regulating impulsive responses in the presence of affective information may result from co-morbid ADHD, rather than autism *per se*.

Given that this hypothesis cannot be tested with the current data, future studies employing the Emotional Go/No-Go paradigm in autistic populations should also examine the potential contribution of comorbid ADHD symptoms. This avenue of research could provide an important step towards disentangling the shared and distinct endophenotypes for ASD and ADHD.

Finally, there were no statistically significant associations between ADOS ratings and neutral measures of executive control. These data speak against previous work documenting a significant relationship between communicative symptoms and impaired executive processing in children with ASD (e.g., Joseph & Tager-Flusberg, 2005). As highlighted above, however, the limited statistical power afforded by the present sample is likely to have reduced sensitivity to moderate associations between the variables of interest. Given this limitation, the most accurate inference to draw from these data is that referential communication skills have a stronger relationship with autism symptomatology than generic measures of executive control.

Taken together, these data contribute two key findings to autism literature: (i) they show that impaired perspective-taking abilities on a referential communication task (i.e., DTWM) are significantly associated with diagnostic severity in adults with high-functioning ASD; and (ii) that the DTWM has greater sensitivity in detecting autism symptomatology relative to neutral measures of executive control.

### **6.3. Implications for and future research**

Under most legal systems, the benchmark for adulthood is set at 18 years of age. However, the past decade has witnessed a growing corpus of research suggesting that adolescent brain development continues beyond the legal age of majority (Giedd et al, 1999; Sowell et al., 1999). In particular, neuroimaging studies have shown that the prefrontal networks underpinning higher-level processing, such as social cognition and executive control, continue to mature well into the third decade of life (e.g., Casey, et al, 2008; Giedd et al, 1999; Gogtay, et al, 2004; Johnson et al, 2009). Consistent with these data, behavioural studies have also revealed age-associated improvements across multiple facets of higher-order cognition between preadolescence and adulthood (e.g., Anderson et al, 2001; Dumontheil, et al, 2010; Huizinga, et al, 2006; Tamm, et al, 2002; Thomas et al, 2007). The studies reported in Chapter 2 contribute to and

strengthen this perspective by demonstrating evidence of age-associated improvements across multiple domains of social and executive processes during the mid-to-later stages of adolescence and young adulthood. Together, these data challenge the enduring notion that the human brain reaches adult-level maturity by 18 years of age.

In addition to deepening our understanding of social and executive function development during adolescence, this avenue of research may also present significant implications for policy. For example, education and childhood services are primarily anchored around the legal age of adulthood. Given the lack of empirical evidence supporting 18 years of age as a marker for adult-level maturity (Johnson et al., 2009), there is a risk of young individuals failing to receive adequate support during this complex transitional period. Whilst empirical research has more recently increased awareness of development continuing beyond 18 years (e.g., the extension of duties on social care and education for children with special education from 18 to 25 years in England [The Children and Families Act 2014]), there remains important gaps in the evidence-base necessary to effectively and comprehensively inform government policy.

Indeed, as highlighted by Johnson and colleagues (2009), an important step for future investigations is to design studies which link brain development to behavioural changes and real-world outcomes. Specifically, it will be important for studies to employ longitudinal designs to chart the development of social and executive processing throughout childhood and adolescence, and into adulthood in order to establish the point at which higher-order cognition reaches adult-level maturity. Given that adolescence has been highlighted as a period of vulnerability to mental health problems (Paus et al, 2008), it would also be of considerable value to examine how these processes relate to the development of psychological difficulties. Such studies could employ a multi-faceted battery of measures, such as neuroimaging methodology, independent and concurrent tests of social and executive processing, as well as self- and other-report surveys to further understand the impact of these processes on real-world outcomes. It will also be important to assess the influence of higher-order abilities on other outcomes in adult life (e.g., educational attainment, life-satisfaction, physical wellbeing, etc.).

Consequently, a multi-disciplinary approach is necessary to provide a better understanding of the interplay between social and executive processes, and their influence on real-life outcomes. Such investigations will contribute to a growing

evidence-base that could help inform policies directed towards adolescent populations and their successful transition into adulthood.

Whilst there are a great number of studies that have examined social cognition and executive control in those with a clinical diagnosis of ASD, relatively little is known about their association at the subclinical level. In addition, given that researchers' have primarily taken a dichotomous approach to the study of social and executive processing, there is a lack of research investigating the potential interaction between the two constructs.

As discussed earlier in this thesis, there is increasing evidence to suggest that the expression of subclinical autism traits extend beyond relatives of those diagnosed with an ASD into the general population (Baron-Cohen et al., 2001b; Constantino, 2011; Hoekstra, et al, 2011). Indeed, a number of studies have demonstrated support for the continuum view of autism, with findings demonstrating greater psychosocial and cognitive difficulties in typically developing adults with elevated autism traits (Christ, et al., 2010; Gökçen, et al, 2014; Lockwood, et al, 2013). The results obtained from this thesis replicate and extend these data.

Investigating subclinical ASD symptomatology in typically developing populations can therefore be of significant value in broadening the understanding of autism spectrum disorders, as well as the underlying neurocognitive atypicalities that give rise autism-like behaviour. Such avenues of inquiry can have important implications not only for theoretical and clinical purposes, but also in promoting psychosocial well-being. For instance, psychiatric conditions such as depression, social anxiety disorder, ADHD, and OCD, are common among individuals with ASD (Ghaziuddin, Ghaziuddin, & Greden, 2002; Ghaziuddin, et al, 1998; Simonoff, et al, 2008; van Steensel, Bögels, & Perrin, 2011). A similar pattern of difficulties has also emerged from some studies assessing first-degree relatives of autistic individuals. (Micali, Chakrabarti, & Fombonne, 2004; Piven, Gayle, Chase, et al, 1990; Piven & Palmer, 1999). However, studies examining the psychosocial profiles of individuals with subclinical ASD traits remains relatively sparse. Future work should therefore address this gap in the literature by administering a detailed battery of self-report questionnaires in order to probe multiple psychiatric conditions (e.g., depression, state/trait anxiety, social anxiety, OCD, ADHD etc.) in subclinical ASD populations. These investigations may help inform intervention programmes targeting psychosocial functioning in subclinical ASD.

In addition, it will also be important to utilise virtual reality paradigms (i.e., dynamic simulations of real-world social interactions based in everyday life settings) in interventions targeting social functioning among adults with ASD. In Chapter 5, findings showed that ASD participants with higher ADOS scores (specifically on the Social Interaction scale) experienced greater difficulties in adopting another person's viewpoint on a referential communication paradigm. These results highlight the working memory variant of the Director Task as a sensitive measure that maps onto real-world social functioning (i.e., autism severity as indexed by the ADOS). Consequently, more complex virtual reality environments are likely to provide an innovative platform to help modify and enhance interpersonal skills and social cognition among adults with high-functioning ASD. Indeed, this method of intervention has proven effective across a wide range of conditions, such as post-traumatic stress disorder, social phobia, and schizophrenia (Gregg & Tarrrier, 2007; Rothbaum, Hodges, Alarcon, Ready, Shahar, Graap, et al, 1999; Rus-Calafell, Gutiérrez-Maldonado, & Ribas-Sabaté, 2014). More recent investigations have also highlighted virtual reality paradigms as a promising tool for improving social outcomes in ASD (Cheng, Huang, & Yang, 2015; Cheng & Ye, 2010; Kandalaft, Didehbani, Krawczyk, Allen, & Chapman, 2013). However, given that these findings have primarily emerged from child and adolescent populations, high-functioning ASD adults remain considerably under-researched. Therefore, a priority for future research is to address this gap in the literature. Future investigations would also benefit from utilising a wide-range of measures indexing real-life outcomes, such as quality of interpersonal relationships, work-place performance, social network size, and overall quality of life. This will help provide a comprehensive assessment of how virtual reality techniques impact functional outcomes among adults with high-functioning ASD.

Finally, on a more general note, given the heterogeneous nature of ASD and common psychiatric comorbidity, future examinations must ensure that ASD groups are closely matched on comorbid conditions, as well as key demographic variables. These controls will serve to tease apart the 'pure' effects of ASD and understand the role they play in the autism-related symptomatology.

## 6.4 Conclusions

This thesis set out to examine the age-related changes in social and executive processing between the mid-to-later stages of adolescence and young adulthood, as well as to obtain a comprehensive profile of higher-order cognition in clinical and subclinical ASD.

Findings revealed support for the hypothesis that social cognition and executive control abilities continue to mature during the later stages of adolescence. Specifically, age-related improvements were found on tasks assessing mental-state reasoning, facial affect recognition, and multiple domains of executive control (i.e., cognitive flexibility, planning, working memory, and response inhibition).

Findings also showed that typically developing adults and adolescents with elevated levels of ASD traits display a qualitatively similar, though milder pattern of difficulties in social and executive processing abilities to those observed in ASD. Of note, these impairments were independent of co-occurring alexithymia. Subclinical autism symptomatology was also associated with variability in processing social information in the context of executive control, and, once again, these impairments were established independent of trait alexithymia.

Extending the use of dual assessment tasks to a clinical sample revealed ASD-specific impairments in higher-order cognition. Findings showed that compared to neurotypical controls, high-functioning adults with ASD were significantly poorer on a referential communication task performed under varying levels of cognitive load, and were less adept in regulating behavioural responses in the presence of affective stimuli. ASD-related deficits were also observed on neutral executive function tasks (i.e., cognitive flexibility and working memory). However, impairments on these measures were less pronounced relative to the referential communication task providing a concurrent assessment of social and executive processing.

Finally, autism severity was associated with impaired perspective-taking abilities on a working memory variant of the Director Task. In contrast, however, no significant associations were found between autism severity and performance on the Emotional Go/No-Go, or on neutral measures of executive control. Together, these findings demonstrate the referential communication measure as a more sensitive index of social impairments in adults with high-functioning ASD.

To summarise, the studies reported in this thesis contribute to a deeper

understanding of the age-associated changes in social and executive function abilities during the later stages of adolescence, and provide a more comprehensive understanding of ASD-related difficulties in higher-order cognition in clinical and subclinical populations.



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# APPENDICES

## Appendix 1: Rapid Emotion Recognition Test

Stimuli examples:





Task instructions:

*In this Task you will be required to identify peoples' emotions from facial expressions (sad, angry, happy, neutral, disgust, and fear). First there will be a white cross across the screen. Please look at the cross, so you are ready for the face which will be shown. A face will appear on the screen for a very short time, so you must watch carefully. After, 6 buttons will appear that correspond to the six possible emotions. Please click the appropriate button of the emotion you thought you saw as quickly and as accurately as possible. First you will practice 12 trials to get used to the task and learn the location of the buttons. The buttons will be the in the same order in the main experiment. When you are ready to begin the practice please press the space bar.*

Sample trial:

