An investigation of joint attention in autism spectrum disorders and the broader autism continuum

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Authors Declaration

This thesis is the results of the author's original research. It has been composed by the author and has not previously been submitted for examination which has led to the award of a degree.

Signed:

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Acknowledgments

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Previously published work

The findings reported in study 2 have been presented in the following.

Little, G., Bonnar, L., Kelly, S., Lohan, K. & Rajendran, G. (2016). Gaze contingent joint attention with an avatar in children with and without ASD. Conference proceedings, International Conference for Developmental Learning and Epigenetic Robotics.

As per the Regulations for submission according to the University of Strathclyde, I can confirm that I am the first author of all above papers, responsible for all aspects of data collection, analyses and reporting of the research.

Signed:

Table of contents **Page Number**

Author's declaration		i
Acknowledgments		ii
Previously published work		iii
Contents page		iv
List of tables		vii
List of figures		x
Abstract		xi
Chapter 1		
Literature review		
1.1	Autism Spectrum Disorders (ASD)	1
1.2	Autistic traits and the general population	4
1.3	Joint attention	11
1.4	Joint attention in ASD	16
1.5	Attention to social stimuli in ASD	18
1.6	Gaze perception	22
1.7	Neural components of gaze following	24
1.8	Models of gaze perception	26
1.9	Gaze cueing	29
1.10	From gaze cueing to joint attention	51
1.11	The current thesis	62
Chapter 2		

Study 1, Gaze and arrow cueing in adults with higher and lower levels of autistic traits

Experiment 1.1

2.1.1 Introduction 67

2.1.2 Method 71

2.1.3 Results 79

2.1.4 Discussion 90

Experiment 1.2

2.2.1 Introduction 96

2.2.2 Method 97

2.2.3 Results 100

2.2.4 Discussion 115

Chapter 3

Study 2, experiments 2.1 and 2.2. Responding to and initiating joint attention with a virtual character in children with and without ASD

3.1 Introduction 122

3.2 Image stimuli validation 128

3.2.1 Method 129

3.2.2 Results 131

3.3 Methods 136

3.4 Results 154

3.5 Discussion 197

Chapter 4

Study 3, experiments 3.1 and 3.2. Responding to and initiating joint attention with a virtual character in adults with higher and lower levels of autistic traits

4.1 Introduction 211

4.2 Methods 214

4.3 Results 216

4.4 Discussion 234

Chapter 5

General discussion

5.1 Aims of the thesis 244

5.2 Study 1 248

5.3 Study 2 and 3 254

5.4 Theoretical and practical implications 266

5.4 Strengths and limitations 268

5.5 Overall conclusions 271

References 274

List of tables **Page Number**

Table 2.1	Participant characteristics, study 1, experiment 1.1	73
Table 2.2	Mean SRTs, pro-saccade task, study 1, experiment 1.1	84
Table 2.3	Mean error rates, pro-saccade task, study 1, experiment 1.1	85
Table 2.4	Mean SRTs for anti-saccade task, study 1, experiment 1.1	87
Table 2.5	Mean error rates for anti-saccade task, study 1, experiment 1.1	88
Table 2.6	Participant characteristics, study 1, experiment 1.2	98
Table 2.7	Mean SRTs for pro-saccade task, study 1, experiment 1.2	103
Table 2.8	Mean error rates for pro-saccade task, study 1, experiment 1.2	104
Table 2.9	Mean SRTs for anti-saccade task, study 1, experiment 1.2	112
Table 2.10	Mean error rates for anti-saccade task, study 1, experiment 1.2	113
Table 3.1	Mean and Standard Deviation percentage accuracy and *d′* for images remembered, memory tasks 1 & 2	132
Table 3.2	Mean rank values from Kruskal-Wallis analysis, memory tasks 1 & 2	135
Table 3.3	Participant characteristics, study 2	137
Table 3.4	Number of images shown due to programming error	148
Table 3.5	Summary of study 2 procedure	153
Table 3.6	Corsi blocks scores, study 2	154
Table 3.7	Participant characteristics, experiment 2.1	157
Table 3.8.	*d′* and β values, experiment 2,1	157

Table 3.9	*d′* and β means and standard deviations for each JA condition and image type, experiment 2.1	159
Table 3.10	Non-target 'yes' responses, experiment 2.1	161
Table 3.11	Percentage 'On-screen' performance, experiment 2.1	164
Table 3.12	Average total viewing times (ms) for each AOI and JA condition per group, experiment 2.1	164
Table 3.13.	Total viewing times, experiment 2.1	171
Table 3.14	Participant characteristics, experiment 2.2	173
Table 3.15.	ASD & TD group mean percentage of ‘yes’ responses for target and non-target images, experiment 2.2	174
Table 3.16	Percentage 'On-screen' performance, experiment 2.2	178
Table 3.17	AOI total viewing times, experiment 2.2	179
Table 3.18	AOI proportion viewing times per image type, experiment 2.2	183
Table 3.19	Characteristics of all participants completing study 2, experiment 2.2	185
Table 3.20	ASD & TD group mean percentage of ‘yes’ responses for target and non-target images, all participants who completed experiment 2.2	186
Table 3.21	Percentage 'On-screen' performance, all participants who completed experiment 2.2	191
Table 3.22	AOI total viewing times, all participants who completed experiment 2.2	192
Table 3.23	AOI proportion viewing times per image type, all participants who completed experiment 2.2	194

Table 4.1	Participant characteristics, study 3	215
Table 4.2	Corsi blocks scores, study 3	216
Table 4.3	Target presentation on screen %, experiment 3.1	218
Table 4.4	Non-target AOIs, experiment 3.1	219
Table 4.5	Target viewing times, experiment 3.1	220
Table 4.6	Mean *d'* and β values for RJA and IJA, experiment 3.1	220
Table 4.7	Mean *d'* scores for image type in RJA and IJA, experiment 3.1	222
Table 4.8	Mean number of non-target images with "yes" responses, experiment 3.1	223
Table 4.9	Mean *d'* scores per image type. Participants split by AQ communication factor, experiment 3.1	226
Table 4.10	Target presentation on screen %, experiment 3.2	228
Table 4.11	Non-target AOIs, experiment 3.2	228
Table 4.12	Target viewing times, experiment 3.2	229
Table 4.13	Mean percentage accuracy for each image type in gaze followed and gaze ignored conditions, experiment 3.2	230
Table 4.14.	Mean percentage of non-target images with "yes" responses, experiment 3.2	232

List of figures **Page Number**

Figure 1.1	Examples of exogenous and endogenous trials in the Posner cueing paradigm	30
Figure 2.1	Frequency histogram of participant AQ scores, experiment 1.1	73
Figure 2.2	Examples of the visual stimuli for experiment 1.1	77
Figure 2.3	Order and time course of the stimuli presentation, experiment 1.1	78
Figure 2.4	Example of fixation area, experiment 1.1	80
Figure 2.5	Frequency histogram of participant AQ scores, experiment 1.2	99
Figure 2.6	Order and time course of stimuli presentation, experiment 1.2	100
Figure 2.7	Error rates for congruent and incongruent gaze and arrow cues, pro-saccade task, experiment 1.2	108
Figure 2.8	Error rates for congruent and incongruent gaze and arrow cues, anti-saccade task, experiment 1.2	114
Figure 3.1	Avatar versions 1 and 2	142
Figure 3.2	Presentation of an RJA trial	146
Figure 3.3	Presentation of an IJA trial	147
Figure 3.4	Non-target images remembered, ASD and TD group, experiment 2.2	177
Figure 4.1	Frequency histogram of participant AQ scores, study 3	215
Figure 4.2	Interaction between JA condition and AQ group split on “imagination” factor, experiment 3.2	234

Abstract

Deficits in joint attention (JA) are among the key characteristics of autism spectrum disorders (ASD). Successful joint attention involves responding to (RJA) and initiating (IJA) joint attention with another person to coordinate attention to the referent object. Eye gaze is one of the most important social cues for RJA (e.g. following gaze to an object) and IJA (e.g. looking towards an object). This thesis aims to explore gaze following and the effects of RJA and IJA in children with ASD, typically developing children and typically developing adults with higher and lower levels of autistic traits. Three studies measuring eye movements and cognitive processing during cueing tasks and simulated joint attention tasks are reported. The first study uses gaze and arrow cueing tasks to investigate the relationship between autistic traits and overt visual orienting to gaze cues in the typical population. The following two studies use a novel gaze contingent computer avatar to investigate how children with and without ASD and adults with high and low levels of autistic traits both respond to and initiate joint attention. Participants gaze behavior as they respond to the avatar's gaze shift (RJA) and direct the avatar's gaze (IJA) towards a referent image is measured and compared. The effect of RJA and IJA on memory for the referent image is explored. Findings suggest that individuals with high and low levels of autistic traits do not differ in how the referent image is remembered in RJA and IJA conditions. Rather, they may show subtle differences in laterality during reflexive visual orienting to rapidly presented gaze cues. Children with and without ASD varied in how they viewed the referent image in the JA interaction with the avatar. In comparison to the typically developing children, those with ASD looked for less time at the referent image and their memory for it was poorer. Overall, this

thesis contributes to our understanding of joint attention and social information processing in ASD and along the broader autism continuum. This thesis also brings several important considerations for future experimental paradigms for the study of joint attention and gaze in ASD.

Chapter 1: Literature review

1.1 Autism Spectrum Disorder

Autism spectrum disorder (ASD) is a lifelong developmental disorder characterised by profound impairments in social interaction, communication and restrictive, repetitive behaviours (American Psychiatric Association [APA], 2013; IDC-10, 2015). With increased awareness and development of diagnostic concepts, global prevalence of ASD diagnoses has grown vastly over the past few decades (Elsabbagh et al., 2012; Kim et al., 2011). Recent estimates suggest that ASD affects approximately 1.1% of adults (Brugha et al., 2011), and 3.8 per 1,000 boys and 0.8 per 1,000 girls of primary school age in the UK (Taylor, Jick & MacLaughlin, 2013). This is a huge prevalence increase since the earliest UK epidemiological study, which reported 4.5 per *10,000* children as having ASD (Lotter, 1966). This rise in prevalence has led the UK research community and government authorities to highlight the need for a more complete understanding of ASD (Pellicano, Dinsmore & Charman, 2014) and set autism as a national priority (e.g. 'Think Autism', UK Dept. of Health, 2014; 'Scottish Strategy for Autism', Scottish Govt., 2011; 'ASD Strategic Action Plan for Wales', Welsh Assembly Govt., 2008).

Commonly recognised in early childhood, ASD is diagnosed with extensive behavioural observations and parent consultation. Because there are not yet any reliable genetic or biological diagnostic markers for ASD, the condition is behaviourally defined and diagnosed. Early and current social skills, receptive and expressive language, cognitive development and overall levels of functioning are considered throughout the diagnosis process (Lord & Bishop, 2009). Recent publication of the updated DSM-V (APA, 2013), which replaces the DSM-IV-TR (APA, 2000), has heralded significant changes in the diagnostic criteria for ASD. This has been met with a mixed response from the autism community with some researchers and individuals with ASD voicing concerns over access to support services and autism service provisions. Some individuals with Aspergers have also expressed concern that the removal of Aspergers syndrome threatens their personal identity as individuals with Aspergers (Giles, 2014; Grant & Nozyce, 2013; Volkmar & McPartland, 2014). The long-term effects on prevalence ratings and research consistency are also so far unclear (Smith, Reichow & Volkmar, 2015). In the DSM-IV-TR (APA, 2000), conditions of autistic disorder, Asperger's disorder and pervasive developmental disorder- not otherwise specified (PDD-NOS) were classified as distinct conditions that fell under the 'pervasive developmental disorders' category. In the current DSM-V, these have been replaced by a single diagnostic classification of autism spectrum disorder (ASD). Previous to the DSM-V, ASD was considered to comprise a triad of impairments in the distinct realms of social interaction, communication and restrictive and repetitive behaviours. Now, the social and communication elements of the triad have been merged into a single domain and ASD is considered a dyad of impairments in social communication and restrictive and repetitive behaviours. For a diagnosis, symptoms of ASD must be present in early development; however, the new DSM-V criterion includes the new caveat that these symptoms may not become evident until social demands of daily life increase. Social demands commonly increase with age as children are expected to socialise more, when joining nursery or school for example. Furthermore, a distinct diagnostic category of "social communication disorder" has been included in the DSM-V to account for those who may present with social and communication symptoms of ASD without restricted and repetitive interests and behaviours. In this thesis the terms autism spectrum disorder (ASD) and ‘autism’ will be used interchangeably. Where appropriate, specific ‘sub-types’ of ASD (e.g. Asperger’s, PDD-NOS, participant groups described as ‘high-functioning’ or ‘low-functioning’) will be discussed and participants of cited studies will be described as per the original authors’ descriptions.

Overall, ASD encompasses a wide range of symptoms that are differently manifested across the population. For example, restricted and repetitive behaviours and interests may include passions for unusual and esoteric topics (e.g. washing machine mechanisms or traffic lights), the persistent desire to order objects in neat lines or overall limited spontaneous activity. Social communication difficulties can include problems with the reciprocity of social interactions and difficulties interpreting social cues and understanding others’ emotions and intentions. Unusual coordination of eye contact and body language is also a common feature. Consequently, individuals with ASD may show a lack of interest in novelty, have difficulties in communicating and struggle to make and maintain friendships and relationships (APA, 2013). Studies have also shown increased instances of anxiety and depression in the ASD population (e.g. Strang et al., 2012). Although ASD is often described in terms of difficulties, the condition can also include strengths in several domains, sometimes referred to as “islets of ability” (Shah & Frith, 1983, p.619). These include enhanced visual processing, with greater detail focus (e.g. Happe & Frith, 2006; Shah & Frith, 1983), good logical reasoning (Baron-Cohen, 2002) and deep levels of knowledge on specific topics of interest (Miller, 1999;

Rimland, 1978). This can manifest in great success on complex and creative tasks requiring intense focus and good attention to detail and occasionally savant abilities (Miller; 1999; Rimland, 1978).

The expression of ASD symptoms can vary between individuals and across social communication and restrictive and repetitive behaviour categories (Wing, 1988). The severity of symptoms can also vary dramatically, from individuals with intellectual disabilities who may require lifelong support, to those who can live and work independently. Moreover, relatives of individuals with ASD have been found to possess moderate and subclinical personality and cognitive traits that are qualitatively similar to those that characterise ASD (e.g. Constantino & Todd, 2003; Piven, Palmer, Jacobi, Childress & Arndt, 1997). This has led researchers and clinicians to consider ASD as an extreme collection of deficits in social communication skills and restrictive and repetitive behaviours and interests, which lie on a broad continuum including the general population.

1.2 The broader autism continuum, autistic traits and the general population

The continuum view of autism suggests that characteristics of ASD lie on a continuum of behavioural traits that are not limited to individuals in the clinical population (Baron-Cohen, Wheelwright, Skinner, Martin & Clubley, 2001; Wing, 1988). Rather, the continuum approach considers ASD as an extreme collection of traits on this continuum which extends into the typically developing population. This notion has been supported by evidence that autistic traits are continuously distributed across the general population, with individuals with an ASD diagnosis falling at the extreme end of this distribution (Baron-Cohen et al., 2001; Hoekstra, Bartels, Verweij & Boomsma, 2007; Ruzich et al., 2015). Unlike the current diagnostic criteria (DSM-V, APA, 2013), the continuum view represents a dimensional, rather than categorical approach to ASD.

This continuum also incorporates the broader autism phenotype (BAP). The BAP is thought to index genetic liability to ASD and is commonly used to describe relatives of individuals with an ASD diagnosis who may display sub-clinical traits and cognitive characteristics of ASD (Wheelwright, Auyeung, Allison & Baron-Cohen, 2010). Measurement of the BAP and autistic traits in the typically developing population are useful for testing the continuum approach and can help to classify which behavioural and cognitive styles may be specific to ASD and which of these characteristics may extend to the typically developing population with higher levels of autistic traits. This is informative for identifying individual differences in the typically developing population related to autistic traits and may also clarify the cognitive styles that are specific to ASD (Landry & Chouinard, 2016). This will ascertain the extent to which qualitative or quantitative differences exist between typical and ASD populations. As such, investigations of autistic traits in the typically developing population allow researchers to investigate whether ASD is truly a spectrum disorder.

Studies investigating autistic traits have found higher levels of autistic characteristics in parents, siblings and more distant relatives of individuals with ASD (Bolton et al., 1994; Constantino & Todd, 2003; Losh, Childress, Lam & Piven, 2008; Piven, et al., 1997; Wheelwright, Aeyung, Allison & Baron-Cohen, 2010). For example, higher levels of personality traits such as aloofness and tactlessness, greater deficits in social communication and more rigid behaviours have been found in parents of children with autism when compared to parents of children with Down syndrome (Bolton et al., 1994; Losh et al., 2009). Scores on these personality traits are also increased in families with multiple, compared to single instances of ASD (Losh et al., 2008; Piven et al., 1997). Briskman, Happé and Frith (2001) have also found that self-reported preferences for solitary hobbies and reduced interest in social activities were similar for fathers and their sons with ASD. Furthermore, their reduced social abilities and preferences differentiated them from fathers of children with dyslexia.

As well as self-reported personality traits, evidence of the BAP can also be gleaned from investigations of cognitive and social processing styles in relatives of individuals with ASD. A greater tendency for "weak central coherence", a cognitive profile involving preference for local, detail focused visual processing hypothesised to be characteristic to individuals with ASD, has been found in parents of children with ASD compared to parents of children without ASD (Baron-Cohen & Hammer, 1997; Bolte & Pouska, 2006; Happe, Briskman & Frith, 2001). This is evidenced by enhanced performance in detail focused visual tasks such as embedded figures and block design tasks (Baron-Cohen & Hammer, 1997; Bolte & Pouska, 2006; Happe, Briskman & Frith, 2001). Evidence of similar but less extreme deficits in theory of mind and social cognition have also been found in parents of people with ASD (Baron-Cohen & Hammer, 1997; Bernier, Gerdts, Munson, Dawson & Estes, 2012; Losh et al., 2009). Compared to those with no family history of ASD, individuals with relatives with ASD can show poorer performance in the 'mind in the eyes task', an advanced theory of mind task where images of eyes expressing complex emotions must be matched to the correct emotion word (Losh et al., 2009). 'ASD like' processing of social stimuli such as faces and biological motion has also been detected (Adolphs. Spezio, Parlier & Piven, 2008; Dalton, Nacewicz, Alexander & Davidson, 2007; Dawson et al., 2005; Losh et al., 2009; Wallace, Sebastien, Pellicano, Parr & Bailey, 2010), with parents and siblings of children with ASD displaying atypical neural activation and fixation to face stimuli (Dalton et al., 2007; Dawson et al., 2005), poorer facial expression identification, reduced sensitivity to direct gaze (Wallace et al., 2010) and reduced attentional focus on the eyes (Adolphs et al., 2008; Dalton et al., 2007).

As well as quantifying autistic traits in the BAP, research has also explored the expression of autistic traits in the broader typical population. This has shown that even those without relatives with ASD can exhibit high levels of autistic traits and show similar (but less extreme) personality, behavioural and cognitive profiles as individuals with ASD (Ingersoll & Wainer, 2014). Investigations into autistic traits in visual tasks have suggested significant differences between typically developing individuals with higher and lower levels of autistic traits and no known family history of ASD (Almeida, Dickinson, Mayberry, Badcock & Badcock, 2010; Brock, Xu & Brooks, 2011; Grinter et al., 2009; Stewart, Watson, Allcock & Yaqoob, 2009). Again, enhanced performance in the visual domain is apparent in individuals high in autistic traits compared to those with low levels of autistic traits. For example, more efficient completion of the embedded figures task (Grinter et al., 2009), the adapted block design task (Stewart et al., 2009) and visual search tasks (Almeida at al., 2010; Brock et al., 2011) suggests a more ‘autistic’ style of local visual processing in typical individuals high in autistic traits.

Tasks that commonly elicit weaker performance in individuals with ASD can also elicit weaker performance in typical individuals with more autistic traits compared to those with fewer autistic traits. For example, weaker visual perspective taking (Brunye et al., 2012), gaze cueing effects (Bayliss & Tipper, 2005 & 2006; Hudson, Nijober & Jellemam 2012) and increased difficulty identifying emotional facial expressions (Ingersoll, 2010) has been found in those with higher levels of autistic traits. Poorer ability to infer mental states from eyes (Baron-Cohen, Wheelwright, Raste & Plum, 2001) and reduced implicit social learning (Hudson, Nijober & Jellema, 2012) has also been associated with higher levels of autistic traits. In addition to behavioural evidence, the structure and activation of neural components associated with social perception has also been linked with individual differences in autistic traits in the general population (Nummenmaa, Engell, Von Dem Hagen, Henson & Calder, 2012; Von Dem Hagen et al., 2011). Taken together, these findings suggest that features of social cognition and visual attention associated with ASD are also evident in the typically developing population in people with increased autistic traits. Further understanding about these associations will be informative about the range of variability in the typically developing population and could also have important implications for autism research. Investigations of autistic traits in the typically developing population combined with tasks that explore areas of strength and weakness in ASD are helpful for determining the extent of cognitive and behavioural variation associated with autistic traits. Investigating the cognitive profiles associated with autistic characteristics in the typical population and understanding the associated individual differences will be important for supporting and extending the continuum view of autism. If such associations are found this will support a more dimensional view of ASD, rather than a categorical approach. Furthermore, if similar social and cognitive profiles (strengths/deficits/patterns of behaviour) between individuals with ASD and higher levels of autistic traits continue to be demonstrated, investigations of typically developing populations with high levels of autistic traits could also have the potential to further improve our understanding of ASD (Hudson, Nijober & Jellema, 2012). From a practical point of view, investigations of the typically developing population also allow researchers to draw from a larger and more accessible sample to explore the relationship between cognitive, social and behavioural factors and autism phenotype expression (Lundquist, & Lindner, 2017).

It must be noted that the measurement of autistic traits in the typically developing population has been criticised. Some argue that the boundary between sub-threshold traits and the genetic basis of ASD is too unclear (Gregory & Plaisted-Grant, 2013; Losh, Adolphs & Piven, 2011). This argument suggests that it is premature to state that similar personality and behavioural manifestations in individuals with ASD and typical development may reflect similar underlying mechanisms. For example, Gregory and Plaisted-Grant (2013) recently conducted two visual search tasks with an ASD participant group and a TD group high in autistic traits. They did not find similarities in performance across both groups and argue that the expression of autistic traits in the TD population may not necessarily arise from the same underlying mechanisms that elicit these profiles in ASD. Subsequently they caution against viewing the behavioural performance of typically developing individuals with high autistic traits as a "proxy" for behaviour that might be expected in individuals with ASD. Indeed, other studies have also failed to find similar patterns of central coherence (Losh et al., 2009), executive function (Losh et al., 2009; Ozonoff, Rogers, Farnham & Pennington, 1993) and social cognitive skills (Holt et al., 2014) in family members of individuals with ASD. Studies have also failed to find autistic characteristics and cognitive profiles in typically developing samples with higher levels of autistic traits (e.g. Kunihira, Senju, Dairoku, Wakabeyashi & Hasegawa, 2006). Furthermore, where performance in cognitive tasks differ in relatives of people with ASD and individuals high in autistic traits compared to those without relatives with ASD and low in autistic traits, task performance does not necessarily match patterns expected in ASD (Losh et al., 2011; Scheeren & Stauder, 2008).

A clear picture of the specific cognitive and behavioural traits and the extent to which they comprise a continuum including the typical population is further blurred by the heterogeneity in the manifestation of ASD itself. Furthermore, the above findings could suggest a different manifestation of similar underlying mechanisms, which may or may not be the same in ASD and TD individuals high in autistic traits. However, this is where systematically measuring autistic traits in the typically developing population may be useful. Rather than viewing high autistic traits as a proxy for high functioning ASD performance, research measuring autistic traits should further characterise the cognitive, behavioural and neural profiles of those in the general population with varying levels of autistic traits. Current evidence indicates some similarities in social and cognitive task performance between individuals with ASD and typically developing individuals with high levels of autistic traits. Similar subsequent investigations will allow these behavioural and neural associations with autistic characteristics to be further delineated. A better understanding of the subclinical expression of autistic traits will bring further clarity to the expression of ASD characteristics and identify what autistic characteristics are also found in the typical population and where individual differences occur. This will be helpful for testing and advancing diagnostic concepts and theories of ASD, generating hypotheses and expanding our knowledge about the relationship between cognitive styles and autistic traits in both ASD and TD populations.

1.3 Joint attention

At its most basic level, joint attention is coordinated attention with a social partner (Mundy & Burnette, 2005). This is a vitally important social communicative skill, which develops in infancy and aids social interaction and learning throughout the lifespan. Before the age of around 9 months infants engage in 'dyadic joint attention', or face-to-face interactions with social partners (usually caregivers) where their attention is focused on each other (Bakeman & Adamson, 1984; Scaife & Bruner, 1975). As propensity for joint attention increases infants begin to monitor the attention of others, follow their gaze to objects in the environment and check whether others are sharing their attentional focus (Bakeman & Adamson, 1984; Butterworth, 1995; Scaife & Bruner, 1975; Striano & Stahl, 2005). When two individuals coordinate their attention in this way towards a common object in the environment (or the 'referent object') this is known as 'triadic joint attention'. The focus of this thesis will be on triadic joint attention. Henceforth, joint attention (JA) will refer to a triadic interaction involving two individuals and a referent object. Here at least one individual in the JA interaction must purposely view the same object as the other (Bakeman & Adamson, 1984; Butterworth, 1995; Emery, 2000; Frischen, Bayliss &

Tipper, 2007; Leavens & Racine, 2009). However, some researchers argue for an additional layer to this JA definition where both individuals should be aware of focusing on the same referent and on each other (Carpenter and Call, 2013; Tomasello, 1995; Tomasello, Carpenter, Call, Behne, & Moll, 2005). Emery (2000) categorises this type of joint attention as 'shared attention' and Carpenter and Liebal (2011) categorise this as 'knowing together'.

Joint attention provides a wealth of useful social information which can facilitate learning and social referencing. For example, Scaife and Bruner (1975) describe an infant monitoring changes in the gaze of their caregiver. With gaze alterations, the caregiver is able to indicate features in the environment to provide a context for their speech and behaviours. Recognising these and responding to establish a common referent is fundamental for subsequent language, social communication and theory of mind skills, the development of which invariably occurs in the context of joint attention interactions. Accordingly, joint attention has been described as a "staging post" in early social communicative development (Charman, 2003, p. 231), acting both as a 'postcursor' of early communicative abilities like gaze following and as a 'precursor' to more advanced social abilities like theory of mind and language acquisition (Charman, 2003). Indeed, longitudinal and retrospective studies have found that joint attention ability in infancy and toddlerhood can predict later language ability (Brooks & Meltzoff 2005; Mundy & Gomes, 1998; Charman et al., 2000; Brooks & Meltzoff, 2015), social responsiveness (Clifford & Dissanayake, 2008; Travis, Sigman & Ruskin, 2001) and theory of mind (Baron-Cohen et al., 2001; Brooks & Meltzoff, 2015) in both typically developing children and children with ASD. Although a critical developmental milestone early in life, the importance of JA is not limited to infants and young children; it remains a vital component of social and communicative skills throughout the lifespan. Adults and older children unable to follow and initiate joint attention may be impaired in their ability to sustain social interactions, which include quick and subtle changes in the attentional focus of the self and others. Less is currently known about joint attention behaviour in older children and adults, and the empirical literature on joint attention for these populations is comparatively sparse. This may be due to the lack of suitable observation tools and experimental paradigms to measure joint attention behaviours in these populations. Although useful in infant, toddler and early childhood populations, current observational tools are less appropriate and less sensitive for detecting difficulties or differences in joint attention in older children and adults. Determining joint attention capabilities beyond infancy and early childhood in both typical and atypical populations will be important to understand the full range of joint attention ability and the full developmental trajectory of joint attention behaviours. This will allow us to examine how joint attention abilities change and the extent to which early atypicalities may persist or change through childhood and into adulthood. Joint attention plays an important role in the development of social and communication skills and given that these skills and the neural mechanisms underpinning them continue to be refined into adulthood (Blakemore, 2012), studying joint attention in later life is pertinent. Better knowledge of the functioning, neural and behavioural mechanisms and influence of joint attention on related social skills across the lifespan in both the typical and atypical population will provide a better understanding of individual differences in

JA and how these impact behaviour, social understanding and cognitive processing across the population.

Two specific types of behaviours are required for successful joint attention interactions: responding to joint attention (RJA) and initiating joint attention (IJA) (Seibert, Hogan & Mundy, 1982). Both bring individuals' attention to a common focus and play important yet divergent roles in joint attention. RJA involves responding to someone else's directive to a referent. IJA involves directing another person's attention to a referent to cause them to adopt one's own attentional focus. These behaviours include following or initiating gaze, gesture, a head turn, vocalisation or a point from another person to the referent object or event. The same behavioural forms of IJA can be used for declarative and imperative purposes, either to show interest in an object or to make a request about it (Charman, 2003; Mundy, Sigman & Kasari, 1994).

RJA and IJA have different developmental trajectories, with RJA emerging first, followed by IJA (Butterworth, 1995; Tomasello, 1995). Although they have domain general continuity, correlations between them are not always found in very young children and individual differences in development between RJA and IJA are often reported (e.g. Brooks & Meltzoff, 2008; Gillespie-Lynch, 2013; Mundy & Gomes, 1998; Mundy et al., 2007, although see Carpenter, Nagell, Tomasello, Butterworth & Moore, 1998). RJA and IJA are also considered to activate distinct but overlapping visual attention and social cognitive mechanisms associated with interpreting communicative intentions, reward and motivation (Mundy & Newell, 2007; Pfeiffer et al., 2014; Redcay, Kleiner & Saxe, 2012; Schilbach et al., 2010). RJA may be dependent on posterior attention networks involved in involuntary orienting, processing biologically meaningful stimuli and the understanding of communicative intentions (Emery, 2000; Mundy & Newell, 2007). IJA may be more reliant on anterior attention networks involved in voluntary orienting and disengagement of attention (Henderson et al., 2002; Mundy & Newell, 2007). Reward-related brain areas and goal directed attention mechanisms might also be more actively engaged during IJA than RJA in adults (Pfeiffer et al., 2014; Schilbach et al., 2010). The recruitment of social and reward related mechanisms during joint attention highlights the inherent disposition for humans to engage in and share social experience.

Social cognitive theories (Baron-Cohen, 1995; Tomasello, 1995) propose that the development of joint attention reflects stages of emerging social cognition and the developing ability to see others as intentional beings. This then provides the foundation for referential communication and language development (Baron-Cohen, 1995; Tomasello, 1995). One could argue that JA involves rudimentary theory of mind where one must understand that one's own intentions lead to goal-related attentional focus and socially valuable responses and therefore others too have selective attentional focus and an awareness of its social value. The integration of these two sources of information is thought to scaffold social and symbolic development. Indeed, this theory is supported by longitudinal research that shows these associations (Brooks & Meltzoff 2005; Mundy & Gomez, 1998; Charman et al., 2000; Meltzoff & Brooks, 2015, Baron-Cohen et al., 2001). Alternatively, the parallel distributed processing model (PDPM, Mundy & Newell, 2007; Mundy, Sullivan & Mastergeorge, 2009) proposes a more connectionist and constructivist theory where joint attention is positioned as an information processing system that aids self-organisation of social learning. Here, joint attention arises through an increasing ability to integrate information about one's own attention, another's attention and a referent object (Mundy & Newell, 2007). This triadic interaction is practiced throughout infancy, eliciting social learning opportunities and social understanding. This then becomes well integrated as a social information processing system which elicits activation of a widespread anterior and posterior attention networks, supporting social cognition and information processing throughout the lifespan (Mundy et al., 2009). Although these models are complementary, the main differences are in the focus placed on understanding others' intentions and on practice in the representation of triadic relationships (Gillespie-Lynch, 2013).

1.4 Joint attention in ASD

Deficits in joint attention are among the earliest diagnostic indicators of ASD and can be evident before 12 months of age (APA, 2013). These deficits are manifest through reduced eye contact and difficulties orienting towards people. Children with ASD are less likely to respond to bids for joint attention, including reduced following of gaze and pointing gestures. Fewer instances of initiating joint attention are also observed. This includes reduced showing of objects or gesturing and gazing towards them with the sole aim to share interest, however, these behaviours can still be expressed to make requests and demands (Mundy, Sigman & Kasari, 1994). Observational studies and retrospective investigations of childhood home videos have shown that these deficits can discriminate young children who go on to develop ASD from their peers with typical development or with intellectual developmental disorders (Osterling & Dawson, 1994; Osterling, Dawson & Munson, 2002). Indeed, diagnostic and screening instruments for ASD in younger children such as the checklist for autism in toddlers (CHAT; Baron-Cohen, Allen & Gillberg, 1992) and the autism diagnostic observation schedule (ADOS II; Lord et al., 2011) include assessments of behaviours such as the use of eye contact, gaze following and responding to and initiating joint attention.

These deficits are consistently observed in infants and preschool children with ASD and are considered to shape future language and social communication development (Sigman & Ruskin, 1999; Toth, Munson, Meltzoff & Dawson, 2006). Some evidence also suggests that deficits in IJA may be more persistent than RJA deficits, particularly in children with greater general cognitive ability, who often show improvements in RJA (Mundy, Sigman & Kasari, 1994). However, RJA abilities in childhood have recently been suggested to predict social skills and independence in adulthood (Gillespie-Lynch et al., 2012). Less empirical research on joint attention deficits is available for older children and adults, mainly due to a lack of appropriate measurement and observation tools. Bean and Eigsti (2012) recently developed an assessment of RJA for older children and adolescents and found that those with ASD responded significantly less to naturalistic RJA prompts than their typically developing peers, showing less eye contact and fewer instances of triadic joint attention. Hobson and Hobson (2007) have also found reduced joint attention in older school age children with ASD. These methodologies use more subtle observational measures and are more appropriate for assessing joint attention in older populations. These methodological advances mean that joint attention abilities could be measured later in life and studied more longitudinally (Bean & Eigsti, 2012). A better picture of individual differences in joint attention across the lifespan in ASD and on the broader autism continuum will allow for the developmental trajectory of joint attention throughout childhood and into adulthood to be measured and delineated. This will strengthen theoretical perspectives that currently focus on its very early development. Understanding how joint attention and social abilities change throughout the lifespan will help determine if and how associations between early JA and social functioning in adulthood are explained by changes in JA development (Gillespie-Lynch et al., 2012). A deeper understanding of the extent of the deficits that individuals with autism face throughout their lives, how these deficits persist and how they affect social cognitive functioning will also further clarify theoretical perspectives of JA in ASD.

1.5 Attention to social stimuli in ASD

Some researchers have suggested that problems with joint attention in ASD may be an epiphenomenon of early social attention orienting deficits (Dawson, Meltzoff, Osterling, Rinaldi & Brown, 1998; Dawson et al., 2004; Mundy & Burnette, 2005; Mundy & Neal, 2001). This “social orienting” argument (Dawson et al., 1998) proposes that a lack of attentional bias towards social stimuli reduces the social information available to infants with ASD, limiting opportunities for social learning and altering development of social attention (Dawson et al., 1998, 2004; Mundy & Neal, 2001).

To test this theory, eye-tracking techniques have been utilised to compare visual attention to social stimuli in ASD and TD populations. The lightweight and non-invasive nature of modern day eye trackers has led to a dramatic increase in the use of eye tracking techniques to investigate visual attention in ASD (Guillon, Hadjikhani, Baduel & Roge, 2014; Boraston & Blakemore, 2007). In particular this has been a helpful approach for research questions regarding social attention in ASD and has allowed questions about how individuals with autism look at social stimuli to be studied in greater detail than ever before. Eye movements are of particular interest as they are “uniquely poised between perception and cognition” (Richardson, Dale & Spivey, 2006, pp.324). Our eyes move quickly, flexibly and selectively to explore a visual scene and are typically directed towards objects that involuntarily capture our attention or that we voluntarily look towards (Holmqvist, 2011). Objects in our visual field are perceived with maximum acuity at the foveal point of fixation (Leigh & Zee, 2006). The close coupling of eye movements and visual attention means that eye tracking methods provide the most direct and precise measure of visual attention available and allow for inferences to be made about the cognitive processes behind specific tasks (Hayhoe & Ballad, 2005; Hoffman, 1998; Munoz & Everling, 2004; Posner, 1980; Rayner, 2009). As such, eye movements have been linked to several perceptual and cognitive processes including visuo-spatial attention, object perception, memory, decision-making and reading (Duchowski, 2007; Land & Hayhoe, 2001).

Various eye movement measures can be calculated including the number and duration of fixations and saccades, saccadic amplitudes and reaction times, visual scan paths and viewing times for specified stimuli areas of interest (AOIs). The features of eye movements are well defined and well-established neural substrates for oculomotor control provide a strong basis for their classification (Duckowski, 2007; Leigh & Zee, 2006; Rayner, 2009). It must be noted however, that eye tracking captures data from foveal attention and cannot capture covert or peripheral attention.

Nevertheless, there is considered to be a close link between overt and covert attention, where shifts of covert attention are required for shifts of overt attention (Blair et al., 2009; Liversedge & Findlay, 2000). Even so, successful processing of visual information cannot be assumed by eye tracking data because information processing does not necessarily always occur at the fovea (Rayner, 2009). This means that visual attention to a stimulus may not guarantee processing and understanding. Eye trackers also *cannot* inform us directly of the mechanisms behind these cognitive processes. Only with well-designed studies and additional cognitive measures can it be a powerful tool and only inferences informed by theoretical bases can elicit meaningful results. Despite these caveats, eye tracking is the best existing technique to reveal the precise nature and extent of atypicalities in visual attention in ASD (Guillon et al., 2014).

Much of the work investigating social attention in ASD has measured visual attention to scenes including people (e.g. Fletcher-Watson, Leekam, Benson, Frank, & Findlay, 2009; Riby & Hancock, 2009; Rice, Moriuchi, Jones & Klin, 2012). Preferential viewing and visual exploration tasks where social stimuli (e.g. faces, biological motion, scenes with people) are presented for viewing alongside non-social stimuli (e.g. objects, geometric patterns, scenes without people) have suggested a comparatively weaker attentional bias for social stimuli in both infants (Falck-Ytter et al., 2012; Falck-Ytter, Bolte & Gredeback 2013; Klin et al., 2009; Pierce et al., 2011) and children with ASD (Sasson et al., 2008 & 2011), as measured by viewing times to the respective stimuli. These atypical biases may be more subtle in adults with ASD. For example, Fletcher-Watson et al. (2009) found that both ASD and TD adults and adolescents demonstrated strong viewing preferences for social (person-present) versus non-social (person-absent) visual scenes and spent significantly more time viewing the social scenes. However, the ASD group showed a tendency to look less at the face and body in the social scenes and made significantly fewer first fixations to the social elements of the scene, suggesting reduced attentional priority for them.

Scene viewing paradigms have also highlighted reduced attention to faces and eyes in ASD. When adolescents and adults are presented with images of natural social interactions (Hanley, Philips, Mulhern & Riby, 2013; Riby & Hancock, 2008) and video clips of people engaged in conversation (Riby & Hancock, 2009), those with ASD look less at faces compared to both chronological age and non-verbal ability matched control groups. This has also been demonstrated when infants (Chawarska, Marci and Shic, 2012; Shic et al., 2011) and school aged children (Rice, et al., 2012) with ASD view videos of people in naturalistic play and conversation settings.

When viewing a face, individuals with ASD have also been shown to spend less time fixating on the eyes (Corden et al., 2008; Dalton et al., 2005; Hanley et al., 2013; Klin et al, 2002; Pelphrey et al., 2002; Rutherford & Towns, 2008; Spezio, 2007) and more time looking at external facial features or objects in the scene (Kliemann et al., 2010; Klin, Jones, Schultz & Volkmar, 2003; Riby & Hancock, 2008; Wilson, Brock & Palermo, 2010). This is evident in free viewing tasks and emotional facial expression and gender identification tasks (Pelphrey et al., 2002).

These effects, however, are not universal (Elsabbah et al., 2009; Freeth, Chapman, Ropar & Mitchell, 2010; Van der Geest, Kemner, Verbaten, & Van

Engeland, 2002), and reduced social attention seems to be most evident with increases in social content and ecological validity; for example, where the person in a video clip engages the participant directly (Chawarska, Marci & Shic, 2012), where more than one person is viewed in a scene (Riby & Hancock, 2009; Speer, Cook, McMahon & Clark, 2007) or where complex rather than basic emotional facial expressions are displayed (Rutherford & Towns, 2008). In typically developing individuals, increasing the social content of images in this way results in increased fixation on the faces and eyes (Birmingham, Bischof & Kingstone, 2008), this does not appear to be the case in ASD, supporting the notion of impaired social attention in this population.

1.6 Gaze perception

Of the numerous social cues available for joint attention interactions, eye gaze is arguably the most salient and demonstrative communicative signal. The morphology of the eyes and their prominent placement on the face makes eye gaze highly visible to others (Kobayashi & Kohshima, 1997). The contrast between the white area of the sclera and the dark pigment of the iris means that our direction of gaze is clearly visible and detectable. Indeed, gaze following in humans is incredibly precise and subtle deviations in gaze direction can be detected at 2.8 degrees (Bock, Dicke & Their, 2008; Gibson & Pick, 1963). This is thought to be to our evolutionary advantage, for example direct gaze indicates that the gazer is looking at the perceiver. This can convey hostility or attraction, and prolonged gaze is likely to instigate social interaction (Von Grunau & Anston, 1995). Gaze direction also alerts the perceiver to relevant or threatening objects or events in the immediate environment (Kobayashi & Kohshima, 2001).

It is therefore unsurprising that the eyes of others are uniquely efficient in capturing our attention (Friesen & Kingston, 1998; Laidlaw, Risko & Kingstone, 2012). Numerous behavioural and eye movement studies have shown that when viewing faces, attention typically focuses on the eyes (Langton, Watt & Bruce, 2000; Schyns, Bonnar & Gosseling, 2002; Yarbus, 1967). Visual search studies have also demonstrated a "stare in the crowd" effect, where eyes with direct gaze are identified more efficiently than eyes with averted gaze (Conty et al., 2006; Senju & Hasegawa, 2006; VonGrunau & Anston 1995). Task irrelevant faces with direct gaze can also interfere with detection of a non-social target (Langton et al., 2008), further highlighting the captivating effect of gaze. As well as modulating attentional focus, gaze also affects subsequent cognitive processing. For example, attention to the eyes can enhance face processing. Viewing a face with direct gaze facilitates performance in tasks such as gender (Macrae et al., 2002), emotional facial expression (Itier & Batty, 2009) and identity recognition (Farroni, Massaccesi, Menon & Johnston, 2007) and memory (Hood et al., 2003). Interestingly, children with ASD may not show the "stare in the crowd" effect (Senju. Hasegawa & Tojo, 2005; Senju, Yaguchi, Tojo & Hasegawa, 2003) or enhanced gender recognition for faces with direct rather than averted gaze (Pellicano & McCrae, 2009). Adults with ASD also appear resistant to the distracting effects of a face with direct gaze in visual search tasks (Riby, Brown Jones & Hanley, 2012). This evidence suggests that gaze may not typically modulate attention and cognitive processing in ASD.

Gaze is also used to interpret communicative intentions, desires and future actions (Ferri et al., 2014; Senju & Johnson, 2009). As such, it has been described as a "window into the mind" (Shepherd, 2010, pp.10). These are highly social concepts that individuals with ASD can find difficult to understand. However, deciphering motivations and intentions is not required for gaze perception as this can easily be achieved by the geometric, directional qualities of the eye. Nonetheless, the above evidence clearly suggests atypical processing and reduced priority for gaze in ASD. Furthermore, the referential significance of gaze may also be reduced in individuals with ASD. Unlike typically developing infants, infants with ASD may not use eye contact to disambiguate social situations (Philips, Baron-Cohn & Rutter, 1992). Gaze is also less salient when inferring others desires in children with ASD. For example, when presented with a schematic face with averted gaze and arrows directed to one of four objects (usually sweets) and asked which one the face likes, children with ASD are more likely to use the arrow to infer the object preference than TD children who are more likely to use the gaze cue (Ames & Jarrold, 2007; Baron-Cohen, Campbell, Karmiloff-Smith, Grant & Walker, 1995; Rombough & Iarocci, 2013). Because detecting and interpreting eye gaze is vital for the development of joint attention and communicative skills, which are impaired in ASD (e.g. theory of mind, language deficits), atypical gaze perception is a promising hypothesis to explain joint attention and other social impairments in ASD.

1.7 Neural components of gaze following

A growing body of research utilising brain imaging and electrophysiological techniques has uncovered specialised neural circuitry for gaze and joint attention.

This includes visual attention mechanisms, affective mechanisms and social cognitive mechanisms which are deeply entwined with networks involved in face processing and social cognition (Itier & Batty, 2009). One of the key neural components of gaze perception is the superior temporal sulcus (STS, Pelphery, Viola & McCarthy, 2004; Hoffman & Haxby, 2000; Puce, Allison & McCarthy, 1999). Because the eyes are commonly viewed in the context of a face, there is substantial overlap in neural activation found during gaze and face processing. The STS therefore shares reciprocal connections to brain regions for face and emotion perception such as the fusiform gyrus (FG) and the amygdala (Kawashima et al., 1999). The amygdala is a subcortical nucleus associated with processing socially and emotionally salient stimuli (Adolphs, 2003). As such, it has been likened to a 'detection system', on the lookout for socially relevant events such as eye contact and directed eye gaze (Frischen, Bayliss & Tipper, 2007). Together, these structures contribute to what is commonly referred to as the "social brain" (Adolphs, 1999; Adolphs & Spezio, 2006; Brothers, 1990).

Discovery of this "social brain" network has increased awareness of abnormalities in brain structure; function and connectivity in ASD, particularly in the domains of gaze and face processing (Ashwin et al., 2007; Geourgescu et al., 2013; Mundy, Sullivan & Mastegeorge, 2009; Nomi & Uddin, 2015; Pelphery, Morris & McCarthy, 2005; Senju & Johnson, 2009; Von dem Hagen et al., 2012, & 2013). Furthermore, investigations of autistic traits in the typical population have shown differential neural activation between individuals with high and low levels of autistic traits in brain areas associated with gaze following and social understanding (Hasegawa et al., 2013; Nummenaa et al., 2012; Von dem Hagan et al., 2011). This has influenced models of gaze perception in typical and autistic development. Reciprocal connections between gaze following and joint attention both behaviourally and in neural circuitry allow these to be applied to joint attention.

1.8 Models of gaze perception in ASD

The above evidence of weaker attentional biases for social cues in individuals with ASD and the comparative lack of attentional and cognitive modulation when presented with tasks involving gaze stimuli strongly suggests that gaze processing in ASD is atypical. Given that the eyes are an important cue for coordinating visual attention with another person, impairments in gaze perception or atypical modulating effects of gaze are likely to contribute to deficits in JA. Disrupted processing of gaze could have negative effects on the development of JA and social cognition. Theories of gaze perception in ASD have suggested neural and attentional atypicalities that may help to explain the atypical gaze behaviour found in this population.

Affective arousal models

Affective arousal models of gaze processing highlight the impact of gaze on arousal systems. Direct gaze is proposed to evoke amygdala activation (Adolphs, 2003) and increase autonomic arousal (Nichols & Champness, 1971), suggesting a direct and emotional response to gaze. In typical development, this is considered to be intrinsically rewarding, thus reinforcing the strong attentional biases to faces and gaze evident throughout the lifespan (Adolphs, 2003). Affective arousal models suggest that this gaze-modulated arousal is not experienced typically in ASD (Dalton, 2005; Dawson et al., 2005; Kylliainen & Heitanen, 2006). Two separate affective arousal theories have been proposed, hyper and hypo-arousal theories.

Hyper-arousal theory suggests that neural activation caused by gaze is strongly aversive in ASD, causing gaze to become negatively instead of positively valenced, leading to gaze avoidance (Dalton et al. 2005; Kliemann et al., 2010). Conversely, hypo-arousal theory suggests that hypo-arousal of the amygdala prevents the positive association between gaze and reward value (Dawson et al., 2005). Indeed, atypical amygdala activation is evident in individuals with ASD (Dalton, 2005; Dawson et al., 2005; Schultz, 2005) although whether this is due to hyper or hypo-arousal remains unclear (Nomi & Uddin, 2015).

Fast track modulator model

Senju and Johnson (2009a & 2009b) have proposed a fast track modulator model of gaze perception. They suggest that a quick subcortical route for face detection, including the amygdala, mediates the perception of direct gaze. This subcortical route interacts with top down modulation of social context, attention and other task demands and subsequently modulates activation of the social brain including the STS and FG (2009a). These connections become more specific throughout development and Senju and Johnson (2009b) theorise that the structure and connectivity between these subcortical and cortical networks may be atypical in ASD and prevent typical development of the social brain (Senju & Johnson, 2009b). This can lead to weaker immediate modulation from eye contact and atypical subsequent cognitive processing in ASD.

Communicative intention model

The communicative intention model proposes that social deficits in ASD may be caused by a reduced ability to infer intentionality from the gaze behaviour of others (Baron-Cohen et al., 1997; 1995; 2001). For example, Baron-Cohen (1995) proposed a ‘mindreading’ system comprising four modules; the intentionality detector (ID), the eye direction detector (EDD), the shared attention mechanism (SAM) and the theory of mind mechanism (ToMM). This model emphasises the communicative significance of gaze. The EDD represents a supposedly innate ability to detect the presence and direction of observed gaze and the ID functions to attribute intentionality to behaviour. Crucially, the later developing SAM is considered to link these two modules. The SAM builds triadic representations if the self and another are attending to the same object or event. This is then relayed to the ToMM, allowing complex mental states to be attributed to another’s behaviour. According to this model, individuals with ASD are considered to have impairments in the SAM (Baron-Cohen, 1995; 1997).

Attention orienting

An alternative explanation for deficits in gaze following and joint attention in ASD may be general impairments in attentional functioning (Keehn, Muller & Townsend, 2013). This includes impairments in flexibly selecting, engaging, disengaging, orienting and re-engaging attention to social stimuli, causing a negative cascading effect on neural and behavioural development throughout life (Ellison & Reznick, 2012; Keehn, Muller & Townsend, 2013; Mundy & Neal, 2001). Some evidence of deficits in disengaging attention have been found in infants, children and adults with ASD (Courchesne et al., 1994; Elsabbagh et al., 2009; Landry & Bryson, 2004). However, not all investigations of attention disengaging and orienting have found evidence of these impairments (e.g. Fischer, Koldewyn, Jiang, & Kanwisher, 2013). Difficulty with disengaging attention or orienting attention may also account for reduced spontaneous gaze following and poorer joint attention abilities. As such, many studies have used cueing paradigms to investigate visual orienting to gaze in ASD.

1.9 Gaze cueing

The Posner cueing paradigm

The Posner cueing task (Posner, 1980) is the most widely used task to measure visual orienting. Typically computer-based, the task involves the detection, localisation or identification of a target. The target is preceded by a cue (usually a box or arrow cue, presented centrally or peripherally) that indicates the target location correctly (a valid cue) or incorrectly (an invalid cue). Reaction times and response accuracy are recorded. Studies using this paradigm have consistently found that valid cues elicit faster responses than invalid cues (Driver, 1999; Posner, 1980; Ristic, Friesen & Kingstone, 2002), an effect known as the 'validity effect'. This occurs because the cue facilitates an attentional shift in the corresponding direction. Reaction times reflect the time taken to shift attention away from the cued location to the target location and respond (usually via a button press) to the target. Peripheral cueing is considered to be reflexive and elicit a "bottom-up", or exogenous response where attention is attracted by the cue and drawn towards the location of that cue (Remington, Johnston & Yantis, 1992). Centrally presented cues however, are thought to use more endogenous attention (Frischen, Bayliss & Tipper, 2007). In this case, the cue is a symbol that must be interpreted and attention is directed away from the cue to a different location. Endogenous cueing effects emerge more gradually and are longer lasting than exogenous cueing, peaking at around 300ms and lasting for around 1000ms (Muller & Findlay, 1988; Ristic, Wright & Kingstone, 2007). This type of cueing is under “top-down”, or voluntary control. Unlike exogenous cueing where the attentional shift is automatic, responses to endogenous cues can also be more easily supressed (Schuller & Rossion, 2001; Bayliss et al., 2011). Figure 1.1 shows an example of valid and invalid exogenous and endogenous trials.

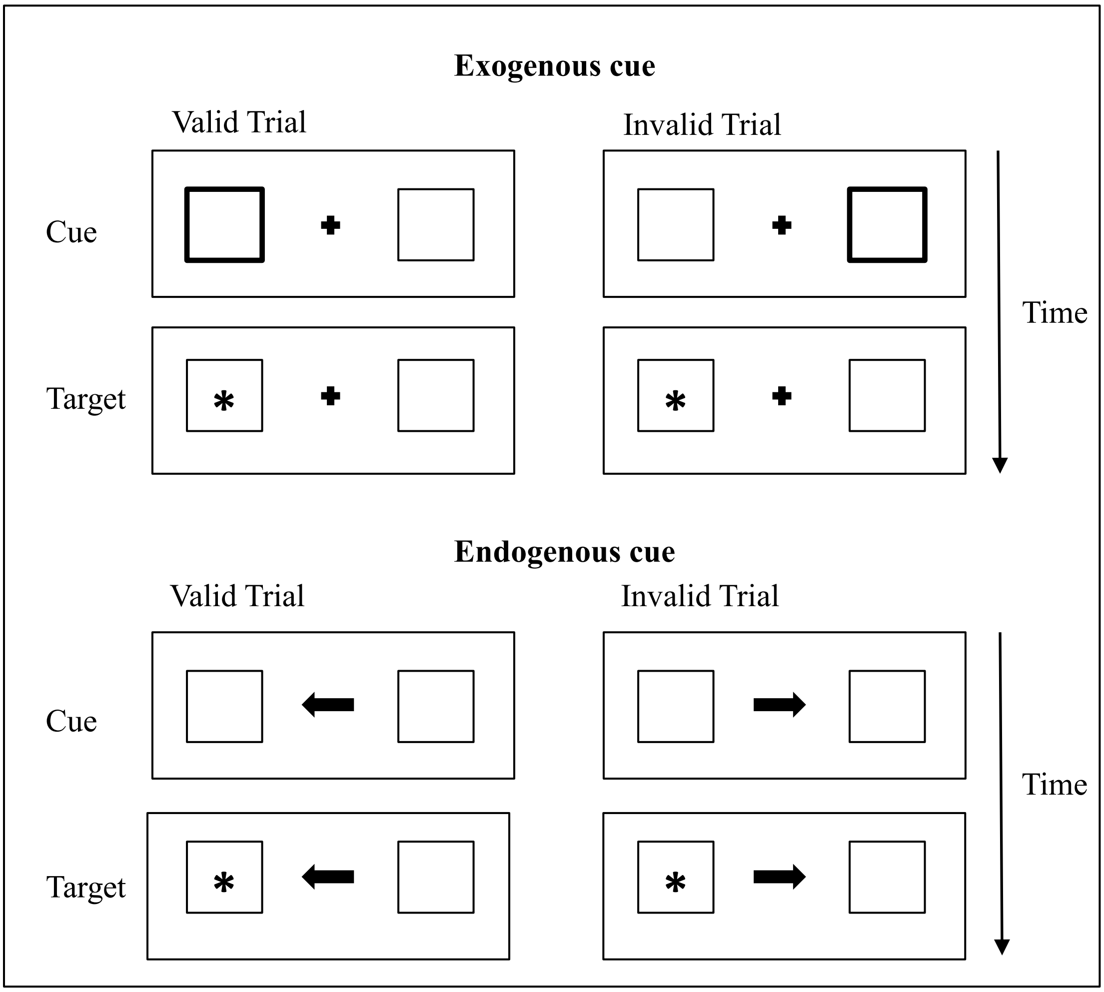

Figure 1.1. Example of exogenous and endogenous trials in the Posner cueing paradigm

The parameters of the Posner cueing paradigm allow visual attention to be modulated in a predictable and measurable way. This has led numerous studies to adapt it to investigate orienting to eye gaze. The gaze cueing task involves a face or eyes presented as the central cue which gaze left or right to cue the target location. The gaze cue can remain present when the target appears, or it can disappear before target appearance to disentangle attention disengaging and orienting. This allows the cognitive mechanisms behind gaze orienting to be isolated and inferences about attention processes to be made. Past research has used many different variations of this paradigm. Static (Langton & Bruce, 1999; Kingstone, Friesen & Gazzaniga, 2000), dynamic (Hood et al., 1998), realistic (Vlamings, Stauder, Van Son & Mottron, 2005) and schematic gaze cues (Kuhn & Kingstone, 2009; Ristic et al., 2005), presented at varying stimulus onset asynchronies (SOAs) have consistently been shown to elicit shifts of attention and incur the validity effect (Driver et al., 1999; Friesen & Kingstone, 1998; Langton & Bruce, 1999). This effect is robust and occurs even if the gaze cue is non-predictive (i.e. it invalidly cues the target 50% of the time) or if the participant is asked to ignore it (Friesen & Kingstone, 1998; Friesen, Ristic & Kingstone, 2004). Consequently, despite the interpretation required for following a gaze cue, orienting to gaze cues is thought to be at least partly automatic. Even if participants are told that a gaze cue is counter-predictive 80% of the time, facilitation effects still occur at SOAs of around 300ms (Driver et al., 1999). This suggests a quick, reflexive response to gaze cueing. However, this reflexive orienting can also be supressed at longer SOAs of 700ms and over (Driver et al., 1999) suggesting a partly voluntary component of gaze cueing.

Gaze cueing in the ASD population

To further examine joint attention deficits and atypical responses to gaze in autism studies have used gaze cueing tasks to investigate reflexive gaze following in ASD. Although it seems intuitive that individuals with autism may respond to gaze cues differently than typically developing individuals, studies have so far elicited equivocal results (Nation & Penny, 2008).

Several studies with participants of varying ages and ASD severities suggest that individuals with ASD do reflexively respond to gaze cues in an apparently similar way to typically developing individuals. For example, Swettenham, Condie, Campbell, Milne and Coleman (2003) found that children with ASD demonstrated a similar validity effect as a TD control group when photographic gaze cues with eyes which appeared to be moving preceded targets. The authors manipulated the cue-target onset times and included SOAs of 800ms and 100ms. They argued that 100ms is too quick to adopt strategic, voluntary strategies for the task and variable SOAs prevented participants from predicting the timing of the targets appearance. The ASD group were slower to respond in the 800ms SOA condition but similar cueing effects between the groups were found at both SOAs. Similar cueing effects here suggest that automatic orienting to gaze is similar in children with ASD and typical development. Kylliainen and Hietanen (2004) also found comparable cueing effects when comparing primary school aged children's performance on a similar task using static photographic gaze cues.

To investigate both voluntary and automatic cueing of attention in ASD, Pruett et al., (2011) compared reaction times in children with and without ASD on peripherally presented box cues and centrally presented gaze and arrow cues. Here, the cue remained present alongside the target. They found that children with ASD were slower overall but demonstrated similar cueing effects as the TD control group when matched for vocabulary and block design performance on the WISC. This suggests that gaze cueing in ASD is intact and may be achieved in a typical way. This is also one of the few cueing studies to control for eye movements to ensure that participants remained centrally fixated as instructed. In doing this, Pruett et al. (2011) found that the ASD group made more saccades and broke more from central fixation. The additional eye movements from some in the ASD group were found to explain their slightly (but not significantly) slower reaction times to the gaze cues. Discounting trials with eye movements, analysis of the properly fixated trials still found robust cueing effects. Furthermore, even when trials with extra eye movements were included in the analysis for non-predictive gaze cues, no effect of diagnosis was found.

Even younger children (Chawarska, Klin & Volkmar, 2003) and teenagers (Okada, Sato, Murai, Kubota & Toichi, 2003) with ASD who show reduced spontaneous gaze following in real life interactions have been found to reflexively orient to gaze cues similarly to matched TD controls. Okada et al. (2003) also investigated gaze cueing in adults with ASD who showed deficits in theory of mind and face-to-face joint attention interactions. Their participants' theory of mind was measured by classic first- and second-order false belief tasks (Baron-Cohen et al., 1985; Baron-Cohen, 1989), which all participants failed. Real life joint attention interaction was determined via parent interviews and an observed lack of eye contact and joint attention with the experimenters. Interestingly, despite deficits in theory of mind and joint attention, these participants all showed typical validity effects suggestive of typical, reflexive attentional shifts. However, these results should be considered with caution as only 3 participants took part in the study.

Taken together, these studies suggest that individuals with ASD extract and respond to directional information from gaze cues in a typical way. However, the evidence is not conclusive. Studies showing differences in gaze following accuracy (Webster & Potter, 2010), atypical laterality (Vlamings et al., 2005), timing and magnitude of gaze cueing (Senju et al., 2004; Swettenham et al., 2001; Goldberg et al., 2008) suggest there may be subtle atypicalities in behavioural responses to gaze cues in ASD. For example, a study by Webster and Potter (2010) presented children and adolescents with and without ASD with images of a person looking at one of three poles. Participants were asked to identify which pole was being gazed at. The difficulty of the task increased as the poles were presented closer together. Older and younger children with ASD performed above chance level but were significantly faster and less accurate in their responses than their age and IQ matched control groups. Interestingly, the older children in the ASD group responded less accurately but more rapidly than typically developing children in the easiest condition, where the poles were furthest apart. This suggests that a developmental delay in gaze processing cannot explain this deficit. Rather this hints at an atypical gaze following strategy in the ASD participants.

Posner style cueing paradigms have also revealed atypical gaze cueing in ASD. Goldberg et al., (2008) investigated gaze cueing in high-functioning children with ASD. Their cueing paradigm included schematic gaze cues and cue-target SOAs of 200ms and 700ms. Despite similar reaction times between the groups, they found no validity effect in their group of children with ASD. In contrast, their group of age matched TD children showed a consistent validity effect at both SOAs. This suggests that unlike the TD group, the group with ASD were not able to take advantage of the directional information provided by the gaze cue in the valid trials. Instead, the direction of the gaze cue did not influence their attention.

Similarly, Ristic et al. (2005) compared gaze cueing for schematic, static gaze cues between adults and adolescents with high-functioning autism and age-matched controls. They found that when gaze cues were 80% predictive, both groups showed the expected validity effect. However, when the cues were 50% predictive, only the TD group showed this validity effect and the ASD group did not. The ASD groups' reaction times were similar for both valid and invalidly cued trials. These results support the notion that TD individuals reflexively orient in the direction of a gaze cue, whereas here, individuals with ASD were more sensitive to changes in the probability of the cues validity than the content of the cue itself. That the participants with ASD oriented 'normally' to predictive gaze, but not non-predictive gaze also hints that more automatic rather than voluntary orienting to gaze may be atypical in ASD. The authors' attributed their findings to reduced social relevance of the gaze cues in the ASD group.

Gaze cues vs. non-social, symbolic cues

Considering the social deficits in autism, researchers have hypothesised that differences in gaze cueing in ASD may be due to the inherently *social* nature of the gaze cue (e.g. Burack et al., 1997; Burack, Enns & Fox, 2012; Ristic et al., 2005; Vlamings et al., 2005). This position is in line with the argument that the social and biological nature of gaze makes it a unique type of cue with gaze specific processing mechanisms, different to those used for non-social cues, which may be atypical in

ASD. Non-social cues are considered to use lower level attention systems, orienting using basic geometric processes, whereas gaze cues are assumed to require additional social processing. To test this assumption, studies have compared behavioural responses to gaze and arrow cues. These cues are comparable as both are symbolic, convey direction and require interpretation. Comparing behavioural responses to both cues allows us to investigate how attentional orienting for gaze cues and non-social, symbolic cues may differ.

Indeed, some cueing studies using gaze and arrow cues in the typical population have demonstrated differences in behavioural responses. For example, incongruent arrows have been reported to evoke weaker cueing effects, unlike incongruent gaze cues (Friesen, Ristic & Kingstone, 2004). This suggests that gaze cues are more resistant to volitional control and may elicit more reflexive, automatic orienting responses than orienting to arrows. Incongruent gaze cues have also elicited longer reaction times than incongruent arrow cues (Ricciardelli, Bricolo, Aglioti, & Chelazzi, 2002; Friesen & Kingstone 2003; Gregory & Hodgeson, 2012). This suggests a gaze specific *social* aspect of attention, supporting the belief that gaze could be a unique attentional cue with its own gaze specific orienting mechanisms (Bayliss, Bartlett, Naughtin, & Kritikos, 2011; Friesen & Kingstone, 2003; Langton & Bruce 1999).

However, this notion has been challenged by studies demonstrating similar cueing effects for centrally presented arrow and gaze cues in the typical population (e.g. Pruett et al., 2010; Ristic, Friesen & Kingstone, 2002; Tipples, 2002 & 2008). This has led some to argue that the eyes are not a “special” cue and simply modulate spatial attention in the same way as arrows.

Investigations into neural activation allow for clarification of the mechanisms that modulate attention to gaze and arrow cues. These mostly suggest that gaze cues may elicit different neural mechanisms than non-social cues (e.g. Heitanen et al., 2006). For example, two patients with disconnected corpus callosa (eliminating communication between hemispheres) demonstrated reflexive orienting to non-predictive gaze cues, but only when they were presented to the hemisphere used for face processing. When the cue was inverted and when cues were predictive 75% of the time, participants showed reflexive orienting in both visual fields. This suggests an interaction between gaze processing and the reflexive nature of the cue whereby automatic reflexive gaze orienting may be lateralised to the face-processing hemisphere, whereas non-social orienting may be more reliant on sub-cortical mechanisms shared between hemispheres (Kingsone, Friesen and Gazzaniga, 2000). In a later study, Ristic, Friesen and Kingstone (2002) investigated how one of these patients oriented to arrow cues. They found evidence of reflexive orienting in both hemispheres. This contrasts with the earlier finding of lateralized gaze cueing and is further evidence that different neural processes may serve gaze and arrow cueing.

Overlapping frontoparietal activation for gaze, arrow and exogenous box cues has been found in an fMRI study by Greene, Mooshagain, Kaplan, Zaidel and Iacoboni (2009) However, they also found that gaze cues alone elicited increased activation in extrastritate areas including the FG and the occipital face area. This again suggests more sub-cortical mechanisms for non-social cues and stronger activation of cortical and ventral mechanisms for social cues.

As well as engagement of face processing mechanisms, brain areas specific for social cognition, such as the temporal-parietal junction (TPJ) show increased activation for gaze cues. The TPJ is engaged when orienting to salient stimuli and is vital for theory of mind and understanding others' intentions (Blakemore & Decety 2001; Saxe & Kanwisher, 2003). Joseph, Fricker and Keehn (2015) found increased activation in the TPJ when participants responded to invalid gaze cues but not invalid arrow cues (Joseph, Fricker & Keehn, 2015). This supports Pelphrey et al.'s (2003, 2005) findings of increased activation in the TJP and reduced activation in the STS when the direction of an observed gaze shift violates the viewers' expectations and does not look at a target. Interestingly, this gaze related difference in neural activation was not found in participants with ASD. Joseph, et al. (2015) also found increased occipital and parietal activation for arrow cues compared with gaze cues, suggesting that arrow cues may require additional top down activation for successful orientation in typical development. Behaviourally, shorter reaction times were found for gaze than arrow cues in this instance.

In the first and only study to investigate neural correlates of gaze and arrow cueing in ASD, Greene et al. (2011) implemented fMRI techniques while participants completed a Posner style cueing paradigm. They found similar behavioural, reaction time responses from children and adolescents with ASD and an age and IQ matched typical control group. However, the TD group showed significantly greater activity in the STS and frontoparietal attention regions for the gaze cues compared to arrow cues. This increase in activity was not evident in the ASD group who showed less differentiation in activation between the cue conditions and increased STS activity for the arrow cues. This is further evidence that gaze cues may not be granted the same attentional status in ASD as they are in typical development. It also suggests that those with ASD distinguish less between social and non-social cues.

Further investigation into differences between responses to gaze and arrow cues may therefore be a useful way of disentangling social and non-social visual orienting in and autism and typical development. Indeed several studies have used gaze and arrow cues in Posner style paradigms when investigating orienting to gaze in ASD.

Comparing gaze and arrow cueing in ASD

Although cueing studies have mostly demonstrated that gaze and arrow cueing is intact in ASD, some offer evidence in support of the idea that individuals with ASD may not process the social nature of gaze in the same way as those with typical development. Here, gaze cues are treated in a similar way to non-social cues in participant groups with ASD but not TD controls. For example, Senju, Tojo, Dairoku & Hasegwa (2004) manipulated the predictive nature of (full face, photographic) gaze and arrow cues. When the cues validly predicted the target 50% of the time, children with ASD had significantly slower reaction times overall than their matched TD peers, although both groups showed similar validity effects. This is in contrast to Ristic et al.'s (2005) findings showing a lack of validity effect in their adult group with ASD. However, Senju et al. (2004) found significant differences between the groups when 80% of the cues were counter-predictive and participants were instructed to look in opposite direction of the central cue. The validity effect for both gaze and arrow cues persisted for the ASD group, whereas for the TD group, the validity effect diminished for the arrow cues compared to the gaze cues. This suggests that eye gaze triggered more reflexive orienting in the TD group who had more difficulty strategically orienting in response to invalid gaze cues. Conversely, the ASD group responded to gaze and arrow cues similarly throughout the task, albeit more slowly, suggesting overall slower processing of centrally presented cues. Overall, both groups responded more slowly to gaze cues than arrow cues.

Vlamings et al., (2005) also conducted a cueing task with gaze and arrow cues. Their participants were adults and adolescents with high-functioning Aspergers, PDD-NOS and a typically developing control group. They found that overall reaction times and congruency effects were similar across the groups. At first glance, these results suggest equivalent cueing in both groups and typical orienting in the ASD group. However, when the groups were considered separately and congruency effects were analysed further, the TD group showed significantly faster responses in the arrows condition than the gaze condition when the cues were congruent. This difference between the cues in the congruent condition was not found for the ASD group. This lack of differentiation between the cues in the ASD groups may suggest reduced saliency for gaze cues in ASD compared to typical development. Furthermore, when the effect of cue direction and target location was considered some interesting differences in laterality between the ASD and TD groups were found. For typically developing participants, the congruency effect was similar for leftward pointing and rightward pointing arrow cues. However, in the gaze cueing condition this effect was significant for rightward gaze cues but not detected for leftward gaze cues. No such differences in laterality were found for gaze cues in the ASD group. Interestingly though, an asymmetry in congruence was instead found in the arrows condition. This suggests that arrows cued the attention of the ASD group in the same way that gaze cued the TD group. These differences were also found when the ASD and the PDD-NOS groups were considered separately. A recent follow-up study with a similar task and exactly the same cueing stimuli and SOAs has demonstrated similar findings in a sample of children with and without ASD (Stauder, Bosch & Nuij, 2011). Here, typically developing children demonstrated asymmetrical rightward congruency effects for gaze cues and symmetrical congruency effects for arrow cues as demonstrated by typical adults. Similarly to the adults with ASD, children with ASD demonstrated significant congruency effects for rightward but not leftward arrow cues. They also demonstrated the opposite congruency effects for gaze cues than the TD children showing significant leftward but not rightward congruency effects. This may be reflective of different processing strategies between the ASD and TD groups for completion of the task. The authors suggest that the ASD group perhaps use a more “non-social” mechanism for gaze cueing.

In a recent meta-analysis of visual orienting in ASD, Landry and Parker (2013) examined 18 studies using Posner style cuing tasks with exogenous peripheral cues and endogenous gaze and arrow cues. Their analysis suggested an overall impairment in orienting in ASD that increased with age and was characterised by slower overall response times. ASD participants also showed a weaker magnitude of gaze cueing than arrow cueing. Interestingly though, comparisons with TD control groups suggested greater orienting impairments for arrow cues than gaze cues. These differences were most prevalent at shorter SOAs. The authors suggests that a focus on non-social cues as well as social cues is required to determine the underlying mechanisms of this orienting impairment.

On balance, the literature suggests that individuals with ASD can demonstrate subtle atypicalities in orienting to central cues, including gaze cues. It is possible that atypical and non-social compensatory strategies may be used to complete gaze cueing tasks. For example, the projection of social expectations or inference is unnecessary for successful gaze following. The subtle differences found in some studies (Senju et al., 2004; Stauder et al., 2011; Vlamings et al., 2005) suggest that non-social mechanisms could be at play when individuals with ASD orient to gaze cues.

The differences demonstrated by investigations of neural processing in gaze and arrow cueing and the less definitive behavioural findings suggest that any differences in attentional processing may not always manifest themselves in manual, button press reaction times. However, the variation in types of cues used (schematic vs. real images, moving vs. static), the methodology of the cueing tasks and the heterogeneity of ASD participant groups obscures any firm conclusions. One potential explanation for the lack of consistent behavioural findings from gaze cueing tasks may be because of how participants are typically asked to respond to these tasks. Most commonly, participants are asked to covertly attend to targets by maintaining central fixation and avoiding making eye movements. Reaction times are measured using button presses and the allocation of attention is inferred. This may not be sensitive or direct enough to measure different attention strategies, particularly if the differences are very subtle. In recent years, eye-tracking techniques have been used to measure overt visual orienting to gaze where an eye movement response towards the target is made. Our eye movements are intrinsically linked to cognitive processing and our allocation of visual attention (Hayhoe & Ballad, 2005; Munoz &

Everling, 2004; Posner, 1980). Eye movements are also faster than other motoric responses, so for inferring attentional allocation they are more precise than button press reaction times (Hunt, VonMuhlenen & Kingstone, 2007). Several studies have used eye-tracking methods to measure oculomotor responses to cueing tasks. These tasks calculate saccadic reaction times (SRTs) to target stimuli. This has revealed validity effects consistent with covert cueing tasks using manual reaction time responses (Mansfield, Farroni & Johnson, 2003). Recording eye movements during these tasks allows visual attention to be measured from cue presentation to target onset. This is not possible with manual responses. Recording eye movements therefore provides richer detail about orienting and focus of attention than button press responses.

These voluntary saccade tasks can also be paired with centrally presented distractor gaze cues. Another advantage of oculomotor control during gaze cueing is that eye movements are more comparable to the naturalistic responses one would make to another's eye gaze in real life settings. Here participants are typically presented with a fixation point with two targets either side. The fixation point changes colour to indicate which side of the screen they should make a speeded saccade toward. A task irrelevant congruent or incongruent gaze cue is presented simultaneously or just before the colour change. Ricciardelli et al. (2002) were the first to investigate whether viewing non-task related gaze and arrow cues could interrupt these goal-driven saccades. As expected, responses were less accurate when the distractors were incongruent than congruent, an effect that was more pronounced when the distractors were gaze than arrows. This suggests that viewing a gaze shift may evoke attentional shifts in the corresponding direction, even if this is not goal oriented. It also suggests that a centrally presented gaze cue may be more distracting than an arrow cue.

No study has since replicated Ricciardelli et al.'s (2002) findings. Kuhn and Benson (2007) used a voluntary saccade task with colour changing fixation and gaze or arrow cues presented simultaneously as distractors. The expected validity effects were found, but no differences in saccadic reaction times or erroneous saccades between the gaze and arrow cues were found. This suggests basically similar oculomotor responses for both social-biological and non-biological cues. These findings have since been replicated by Kuhn and colleagues with gaze and arrow cues of various cue-target predictability (Kuhn & Kingstone, 2009; Kuhn et al., 2010). However, examination of erroneous saccades suggested significantly faster erroneous saccades than correct saccades in the gaze condition. For the arrow condition, the latency of erroneous and correctly directed saccades was not significantly different, again suggesting shifts in attention triggered by gaze cues may be more reflexive (Kuhn & Benson, 2007).

The only gaze cueing study to use a voluntary saccade task with participants with ASD was also conducted by Kuhn and colleagues (2010). Their findings suggest similar gaze cueing in high functioning adults with autism and typically developing controls. Here, the saccade instruction was paired with non-predictive gaze or arrow cues. During gaze cue trials, a schematic face (a circle containing two empty circles as eyes) with no pupils was shown around the fixation point. Pupils and the saccade direction instruction were presented concurrently, showing the face gazing either towards or away from the cued location. Findings revealed no significant differences between the groups in the speed or orientation of saccades and no difference in responses to gaze and arrow cues. This suggests typical gaze cueing in individuals with ASD and no apparent gaze specific response.

This was unexpected given atypical responses to gaze reported in individuals with ASD. This also does not support behavioural and neurological evidence suggesting gaze cues and arrow cues may be processed using different functional, neural mechanisms, thus refuting the argument for a gaze specific attention mechanism. However, one criticism of this study is the presentation of appearing and disappearing pupils in the gaze cue. This may have reduced the intended social saliency of the face allowing participants to view it as a non-social cue. Also, here, participants are asked to focus on the fixation point, wait for and interpret a colour change while ignoring the distracting cue. This could make the fixation point a competing stimulus that may obscure any changes in attention caused by the distracting gaze or arrow cue itself. Furthermore, this is a rather simple task where the participant must generate voluntary saccades, the ease of which may obscure any behavioural differences.

A task with greater cognitive demands perhaps more appropriate for this kind of investigation could be the anti-saccade task. While a pro-saccade task asks participants to make a rapid saccade towards a target, the anti-saccade task requires participants to instead make a saccade in the opposite direction. Both of these tasks involve the organisation, preparation and execution of saccades. However, the anti-saccade task has the additional demand of inhibiting a saccade towards the target and initiating a gaze shift in the opposite direction. This means that the anti-saccade task separates the automatic encoding of the stimulus and the voluntary preparation of a response, thus recruiting both bottom-up and top-down control of attention and allowing the voluntary component of occulomotor control to be analysed separately (Munoz & Everling, 2004). The anti-saccade task is more difficult than the pro-saccade task as it requires inhibitory control of eye movements. As such, the anti-saccade task tends to incur more errors and longer reaction times than the pro-saccade task (Munoz & Everling, 2004). Good oculomotor control is important for efficient and adaptive responses to the ever-changing visual environment replete with dynamic social cues requiring various levels of attention and response. The anti-saccade task therefore better reflects the influences on saccadic orienting in real life settings.

Koval, Thomas and Everling (2005) used an anti-saccade and pro-saccade task with non-predictive gaze cues where fixation point colour determined whether typically developing participants looked towards or away from a subsequently presented target. They found faster SRTs in the pro-saccade trials for congruent cues than incongruent gaze cues, reflecting the validity effects typically found in covert orienting paradigms. Interestingly, in the anti-saccade trials, they also found faster SRTs and fewer errors for congruent compared to incongruent gaze cues. This result implies that participants prepared a saccade in the opposite direction of the cue in anti-saccade trials. This suggests that the effects of gaze cues on saccadic responses may be task dependent. Replicating and extending Koval et al.'s (2005) findings, Gregory and Hodgeson (2012) used a series of anti-saccade tasks including social, biological and non-social cues. They used gaze, a pointing finger, a pointing arrow and words ("left"/ "right") as their cues. Here a colour instruction for the fixation point was not used, instead stimuli presentation was similar to the classic Posner cueing task except participants were asked to make a saccade away from the target.

They found that gaze cues but not arrow cues elicited faster responses in the opposite direction to the cues at SOAs of 100ms, 300ms and 800ms. This was demonstrated by a significant interaction between congruency and cue type where congruent and incongruent SRTs were significantly different for gaze cues but not arrow cues. In addition, pointing finger cues also elicited a similar effect as the gaze cues. This was not reflected in the error rates, where differences between the cues were not statistically significant. Overall, this study suggests that biological cues, but not non-biological cues may influence saccadic reaction times in the anti-saccade task. If social and biological cues have "privileged access" (p.13) to the oculomotor system as suggested by Gregory and Hodgeson (2012), investigating gaze and arrow cueing using eye tracking techniques and the more difficult anti-saccade task may help uncover non-social mechanisms used by individuals on the autism spectrum to follow gaze cues.

Gaze cueing and the broader autism continuum

Investigations into gaze cueing and the broader autism phenotype have compared performance in parents of children with and without ASD and participants with varying levels of autistic traits. This has suggested possible differences along the broader autism continuum. In the same cueing task used by Vlamings et al. (2005), parents of children with ASD showed opposite gaze cueing patterns found in TD individuals in Vlamings et al.'s (2005) experiment (Scheeren & Stauder, 2008). They displayed left (instead of right) lateralised congruency effects for the gaze cues and showed significant congruency effects for the arrow cues. Furthermore, fathers of children with ASD demonstrated significantly slower reaction times to gaze cues than fathers of children without ASD. This suggests atypical gaze processing in the broader autism phenotype that can be detected by a gaze cueing task. However, one caveat might be that AQ scores did not differ between parents with autistic vs. not autistic children.

Some evidence also suggests individual differences in gaze cueing in the broader TD population as a function of autistic traits. For example, Bayliss, DiPellegrino and Tipper (2005) presented gaze (images of avatar faces) and arrow cues, which were valid 50% of the time. These cued one of two letters which participants were asked to make a speeded button press response to. They found that males showed an overall weaker cueing effect for both cues. A subgroup of their participants was also given the AQ questionnaire and significant negative correlation between gaze cueing and AQ score (at an SOA of 700ms) was found. No such correlation was found for arrow cueing. This suggests that those with higher levels of autistic traits may show weaker reflexive gaze cueing than those with lower levels of autistic traits.

Support for subtle variations in visual orienting styles along the broader autism continuum are also demonstrated by manipulating the target stimuli and emotional content of the gaze cue. For example, typically developing individuals high in autistic traits demonstrate stronger cueing effects (i.e. a greater validity effect) towards scrambled images of faces and tools than intact images, whereas the opposite is found in those low in autistic traits (Bayliss and Tipper, 2005). Although responses were similar here when gaze and arrow cues were used, these findings suggest less of an attentional bias towards faces for those with high levels of autistic traits and a preference for local detail than global detail. This links with the weak central coherence theory of ASD and the enhanced processing of small local details found in ASD.

In the typically developing population, faces with fearful expressions can elicit greater cueing effects than neutral faces (Fox, Russo & Dutton, 2002; Matthews et al., 2003), this effect has been found in individuals reporting fewer autistic traits but not in individuals with comparatively higher levels of autistic traits (Miu, Pana & Avram, 2012). This suggests that the social relevance of the facial expression did not affect its processing for participants with high levels of autistic traits. In contrast, Lasalle and Itier (2015) found that orienting responses to gaze cues with happy facial expressions was negatively correlated to AQ score, but not fearful faces. This correlation was found for the full AQ score and for the subcomponents 'attention to detail' and 'imagination' when subcomponents were separated.

Additionally, ERP components commonly associated with attention were measured. The commonly found congruency and laterality effects for P1, a component indicative of an attention shift which is enhanced in congruent cueing conditions and 'ADAN', an ERP component sensitive to attention being held at the target location were found in individuals with low AQ score but not high AQ scores. This suggests that less attention may be directed to gazed at directions in those with high vs. low levels of autistic traits.

Individual differences in autistic traits can also affect performance on tasks requiring higher level social processing. For example, Hudson, Nijboer and Jellema (2012) examined implicit learning of the temperament of two characters that cued targets non-predictively. The disposition of the faces was either pro or anti-social.

This was introduced to participants by showing videos of the characters gazing from the left or right of the screen to the centre to look directly at the participant. The pro-social character began with an angry facial expression, which changed into a happy facial expression as they looked towards the participant. The anti-social character showed a happy face when looking away from the participant, which changed to an angry expression as they looked towards the participant. They found that participants with lower AQ scores were cued less effectively by the anti-social than the social face. Those with higher AQ scores however, showed no difference in cueing between the anti and pro-social characters, suggesting significantly reduced bias for the social information communicated by the characters. As well as behavioural evidence, recent brain imaging studies have also suggested that autistic traits can predict neural structure and activity in the social attention network. Specifically, activation and white matter density in the STS has been associated with AQ score (Hasegawa et al., 2013; Nummenaa et al., 2012; Von dem Hagan et al., 2011). The STS is involved in interpreting higher order social processes from gaze and these findings suggest a link between autistic traits and the neural processes behind gaze perception. Taken together these results suggest a continuum of behavioural traits that may extend to perception and neural activation for social stimulus. Though the extent to which these traits affect gaze perception is still unclear. Further research is required to clearly delineate typical social orienting and determine the influence of autistic traits in social and non-social cueing in the typically developing population. Awareness of where differences in attention to these cues occur will be informative for understanding atypicalities in gaze following and for creating and testing hypotheses about attention processes in ASD.

1.10 From gaze cueing to joint attention

Although useful in investigating how gaze modulates spatial attention, these paradigms have their limitations regarding what they can reveal about triadic joint attention. Cueing paradigms exploring joint attention are narrowly focused on the 'responder'. This is not greatly informative about how deeply the referent is being attended to and processed or what effect initiating joint attention with a gaze shift may have on cognitive processing.

The effect of RJA on object processing

The use of more complex target stimuli has demonstrated modulating effects for referent object processing in situations where typically developing individuals both respond to and initiate joint attention with a gaze shift (Bayliss, Matthew, Cannon & Tipper, 2006; Kim & Mundy, 2012). More complex target stimuli and higher-level cognitive tasks can provide richer information about how the referent object and initiator are processed. This has allowed for more focus on aspects of joint attention that traditional gaze cueing paradigms overlook, namely the initiator and the referent object. Gaze cues can affect how these are perceived and processed (Becchio, Bertone & Castiello, 2008; Frischen, Bayliss & Tipper, 2007). Observing a gaze shift can affect evaluative judgments about the face producing the gaze shift and the referent object itself. Studies of typically developing adults show that faces with eyes gazing to cue targets correctly are judged as more trustworthy than those that gaze in the opposite direction (Bayliss, Matthew, Cannon, & Tipper, 2006). This effect was also negatively associated with self reported autistic traits (Bayliss et al., 2006). Higher ratings of trustworthiness are also given to faces when they are pictured being gazed at rather than not gazed at (Kaisler & Leder, 2016). Referent objects viewed under joint attention where a face with direct gaze shifts their gaze to the target object are also rated more favourably than those not viewed under this joint attention or indicated by non-social, arrow cues (Bayliss et al., 2006). Affective evaluations of referent objects are further affected by joint attention and facial expression, whereby objects are judged more favourably when the face looking at them is portraying a happy expression rather than a disgusted expression (Bayliss Frischen, Fenske & Tipper, 2007). Furthermore, this effect is only evident when the face can viably see the object, not if its line of gaze appears obscured by a barrier (Manera, Elena, Bayliss & Becchio, 2014).

This effect may also depend on the sequence of gaze shifts that are presented. For example, van der Weiden, Veling and Aarts (2010) proposed that a three-step gaze sequence would elicit the strongest effect. Here, a face shows direct gaze towards the observer, a gaze shift towards the target object, then gaze directed back to the observer. They found that this sequence increased the desirability of referent objects relative to the observed face looking from the target object to the observer or looking away from the target object or showing only direct gaze. This three-step sequence is in line with Carpenter and Liebell (2011) and Tomasello et al.'s (2005) description of joint attention which begins with direct gaze to demonstrate a communicative intention, followed by a gaze shift to the referent, finished with a 'sharing look' back to the observer (Carpenter & Lieball, 2011; Tomasello et al., 2005, van der Weiden et al., 2010). The authors suggested here that the reference look communicates that the referent is of value to the communicator and the sharing look communicates that the referent may also be of value to the observer. In van der Weiden et al.'s (2010) study, this sequence was not compared to direct gaze with a gaze shift from the observer to the target object alone. However the evidence described above (e.g. Bayliss et al., 2006) suggests that this two-step sequence also influences object evaluations.

Direct gaze preceding the gaze shift towards the referent object seems to be vital for these effects on object processing. Ostensive communicative cues such as direct gaze may also influence the attended properties of the referent object. This was recently demonstrated in a paradigm where participants were asked to memorise the location and identity of 5 objects assembled from variously coloured Lego bricks (Marno, Davelaar & Csibra, 2014). The objects were presented on a table and participants were shown video footage of an actress positioned behind the table. To begin each trial, the actress either gazed towards the participant and waved or held downward gaze while stroking her chin. She then pointed at one of the objects. A blank screen was then displayed, followed by presentation of the actress behind the table with her hands by her side. In the last scene, one object had either changed location or identity. Participants were asked to indicate which object had changed. Overall, performance was better for cued objects. However, the communicative condition where the actress made direct gaze before pointing increased memory for identity changes and impeded memory for location changes. This directional effect was not found for the non-communicative pointing condition. This suggests that the communicative cue selectively modulated attention to and encoding of the referent object (Marno, et al., 2014).

The effect of joint attention on the status of a referent object is also evident from infancy. In a preferential looking paradigm, 9-month-olds consistently showed reduced viewing times to objects they had previously viewed under joint attention conditions compared to no joint attention conditions when both objects were viewed together. Reduced visual inspection of the joint attention object is indicative of increased recognition and familiarity. Conversely, increased looking to the no joint attention object suggests a comparatively greater degree of novelty for the infant (Striano et al., 2006). This is supported by ERP studies measuring slow wave amplitudes, commonly associated with object recognition. Objects previously viewed in response to joint attention elicit reduced slow wave amplitudes indicating reduced novelty and higher levels of recognition (Reid, Striano, Kaufman & Johnson, 2004; Hoehl, Reid, Mooney & Striano, 2008).

Taken together, this evidence shows that responding to a gaze shift can facilitate object processing. The effect that following gaze to an object can have on its status also appears to be strong enough that the properties acquired by the referent object because of joint attention are maintained, even when gaze towards the object has disappeared. This demonstrates the powerful effect that responding to joint attention by following gaze to an object has on its processing.

Research on how gaze is processed in more complicated social scenes than the gaze cueing paradigms has provided some evidence of similar attentional and evaluative biases to gaze direction and gazed at objects in ASD and TD populations. In a recent series of studies by Freeth, Ropar, Chapman and Mitchell (2010), high-functioning adolescents with ASD or Aspergers syndrome and typically developing controls were asked to adjust the frame of a series of photographs to make them “look best”. The critical photographs contained realistic scenes with a person (e.g. someone sitting in a cluttered office) looking at the camera or gazing at an object in the scene. Both groups showed a similar tendency to centre the people in the frame along with the object being gazed at. Participants were also asked to reposition the photographs to how they remembered seeing them before. Again there was a clear bias from both groups to position the person and parts of the scene under gaze direction in the centre of the frame, even when the images were not originally presented this way. Furthermore, when presented with similarly complex photographic stimuli in the context of a flicker task, participants from both groups were faster at identifying the disappearing object in the scene if the person was depicted as gazing at it. This suggests that gaze cueing is intact in individuals with ASD, not only in sparse Posner style paradigms but also in busier, more complex scenes. Taken together, this series of studies indicates attentional preferences to people, their gaze direction and the referent object, which causes similar memory and preference biases in both high-functioning ASD and TD adolescent groups.

Despite these seemingly typical cognitive biases to gaze direction information in adolescents with ASD, studies recording viewing times and fixation patterns suggest that individuals with ASD spend significantly less time than typical controls looking at objects gazed at by others in social scenes (Bedford et al., 2012; Falck-Ytter, Thorup & Bolte, 2015; Fletcher-Watson et al., 2009; Freeth, Chapman, Ropar & Mitchell, 2010; Riby, Hancock, Jones & Hanley, 2013). Some of these studies have found reduced spontaneous gaze following in their ASD participants (Fletcher-Watson et al., 2009; Riby et al., 2013), while others suggest slower first fixations to faces, but typical subsequent patterns of gaze following from the face to the referent object (Freeth, Chapman, Ropar & Mitchell, 2010). However, each of these studies report reduced subsequent attention to the gazed at objects. This finding has been reported in infants who go on to develop social communication problems (Bedford et al., 2012), toddlers (Falck-Ytter et al, 2015), children (Riby et al., 2013), adolescents (Freeth et al., 2010) and young adults (Fletcher-Watson et al., 2009) with ASD, when compared with TD controls. This reduced saliency of the referent suggests weaker joint attention in ASD from infancy into adulthood. Reduced attention to referent objects has also been found in studies where attention to the referent is encouraged. For example, Riby et al (2013) asked lower-functioning participants with ASD and IQ matched controls to view images of people in busy scenes (viewed for 3sec) during a free viewing condition and a cued condition where they were asked to explicitly state what the people in the scenes were looking at. The ASD group showed reduced viewing times to faces, referent objects and other plausible referents in the scene and spent more time looking around the image in both conditions. In the cued condition, although ASD participants were able to modify their gaze behaviour and look at the face to answer the question, this did not increase their subsequent viewing times of the referent object. Their accuracy in identifying the referent was also lower than the TD group. This common finding of reduced attention to the referent object may reflect difficulties in understanding of the socially mediated, referential nature of gaze. It may also mean that individuals with ASD (perhaps particularly those on the lower-functioning end of the spectrum) could benefit less from the facilitative effects of responding to joint attention found in typical development. Following gaze is a crucial part of RJA, but a failure to use this to make judgments about or prioritise the referent could have detrimental effects on social cognition, memory and learning.

The above research examines responding to a gaze shift towards an object, however, joint attention is also achieved by the initiation of a gaze shift towards an object. This action can deliberately or incidentally provoke an intentional or automatic change in another’s focus of attention. Compared with RJA, the cognitive effects of IJA are less well known. Experimental studies have generally used paradigms that elicit gaze following or emulate responding to joint attention (RJA), resulting in a comparative dearth of knowledge about how individuals initiate joint attention (IJA).

The effect of IJA on object processing

Recent advances in gaze contingent eye tracking and virtual reality technology have introduced more interactive experimental paradigms, better equipped to capture the reciprocity of joint attention interactions (e.g. Bayliss et al., 2013; Edwards, Stephenson, Dalmaso, & Bayliss, 2015; Kim & Mundy, 2012; Pfeiffer et al., 2014 & 2013; Redcay, Kleiner & Saxe, 2012; Schilbach et al., 2010; Wilms et al., 2010). Experimental setups on computer screens, virtual reality headsets and in fMRI machines have been paired with social stimuli including images and video of real people and controllable social avatars. Eye tracker feedback allows the social stimuli presented to respond to participants gaze shifts in real time. This provides an exciting opportunity to emulate joint attention and isolate measurable instances of IJA in a controlled experimental setting.

So far, utilisation of these techniques has revealed interesting neural and behavioural similarities and differences between RJA and IJA. Both forms of JA activate distinct and overlapping visual attention and social cognitive mechanisms associated with interpreting others’ intentions, reward and motivation (Pfeiffer et al., 2014; Redcay, Kleiner & Saxe, 2012; Schilbach et al., 2010). Furthermore, reward related brain areas and goal directed attention mechanisms may be more actively engaged during IJA (Pfeiffer et al., 2014; Schilbach et al., 2010).

Similarly to RJA, responses elicited from one's own initiations of joint attention can affect how attention is subsequently allocated. In a novel task with an IJA twist on the classic gaze cueing paradigm, typically developing adults were asked to move their eyes from a fixation point at the bottom of a screen to an object appearing in the centre. Faces either side of the object then shifted their gaze left or right, half following the participants' gaze shift and half looking in the opposite direction. Tasked with determining a target letter that subsequently appeared on either the left or right face, participants were consistently faster when it appeared on the face that responded to their gaze shift (Edwards et al., 2015). This suggests that participants' attention was preferentially directed to faces that followed their gaze shifts. Furthermore, this effect was significantly weaker in those with higher levels of self-reported autistic traits. This finding mirrors that of the traditional gaze cueing paradigm demonstrating that as well as preferentially attending to the location of an observed gaze shift we also preferentially attend to faces that follow our gaze. This is further evidence of an attentional system with a seemingly intrinsic motivation for joint attention, which may be attenuated with higher levels of autistic traits. Interestingly, this orienting effect was not found when the central object remained as a fixation point. This distinction between simple gaze reciprocity and joint attention to an actual object highlights the importance of the referent object in the triadic joint attention interaction. The object may be important here because when gaze is initiated or followed to an object rather than a blank space we expect our social partner in the interaction to think about or act on the object they are attending to.

As with RJA, eliciting a joint attention response from a face can also affect evaluations and memory for the responder and the referent. When presented with a face flanked by two objects, faces that consistently follow participants' gaze to their chosen favoured objects are preferred to faces that consistently look to the opposite object (Bayliss et al., 2013). These instances of IJA also increase the likelihood that this object will be chosen again and rated more favourably than when the central face does not respond to the participants gaze shift (Bayliss et al., 2013). In a recent, novel virtual reality paradigm, Kim and Mundy (2012) developed a virtual avatar that could emulate both RJA and IJA. Typically developing adults either directed or followed the avatar's gaze to a series of target images of faces, houses and abstract patterns and subsequently their memory for the target images was tested. Findings suggested enhanced recognition memory for house and abstract images in the IJA condition, i.e. when participants' gaze was followed to the image by the avatar. This suggests that having a gaze shift reciprocated in IJA enhanced depth of encoding relative to RJA.

Mundy, Kim, McIntyre, Lerro and Jarrold (2016), replicated this study on groups of high-functioning children with ASD, attention deficit hyperactivity disorder (ADHD) and typical development aged between nine and 13 years old. As in their study with adults, the children were asked to follow and guide a virtual avatar's gaze shift to a series of target referent images to be remembered for a subsequent memory test. TD children and those with ADHD symptoms showed significantly better memory for target images in the IJA condition than the RJA condition. This was demonstrated in a greater number of target image hits in the IJA condition than the RJA condition. The author's proposed two potential explanations for enhanced recognition memory in the IJA condition, one being that increased self-referenced processing in the IJA condition may facilitate better organisation of information (Mundy & Jarrold, 2010). Alternatively, the experience of being under the attention of another (even an avatar) may lead to enhanced activation of the social brain networks involved in gaze processing, thus enhancing information processing (Senju & Johnson, 2009). This effect was not found for children with ASD who did not benefit from enhanced information processing in the IJA condition. Although the children with ASD were able to engage in JA with the avatar, this did not modulate their information processing in the same way as typically developing individuals. This suggests atypical information processing during JA interactions in individuals with ASD, an impairment which may be most pronounced for IJA.

These pioneering studies highlight the importance of RJA and IJA in supporting information processing, and suggests they may do this in potentially different ways. RJA is better delineated than IJA. Further investigation of IJA, how it affects stimulus encoding and to what extent this differs from RJA is required. Given the evidence that autistic traits can influence joint attention abilities (Bayliss, DiPelligrino & Tipper, 2005; Edwards et al., 2015), it will also be informative to conduct investigations of RJA and IJA which include individuals from the typically developing population with high and low levels of autistic traits. This will extend our knowledge by providing a better understanding of typical variation in joint attention behaviours. Joint attention research in general has typically focused on early childhood therefore less is know about joint attention in adulthood. Investigating the effects of autistic traits on the typically developing population will therefore be an important step in advancing this field. This will uncover more about the underlying processes of joint attention in adulthood and whether these differ as a function of autistic traits and may be considered as part of a continuum which could extend from ASD to those in the typically developing population with high autistic traits. Furthermore, investigations like this will have implications for both typical and autistic populations. This will be particularly illuminating in ASD research. ASD is characterized not only by poorer perception and response to RJA but by a lack of spontaneous initiation and expression of social behaviors. Early evidence suggests that object representations and encoding, which appear to be enhanced and modulated by joint attention in typical development, may be reduced in ASD (Mundy et al., 2016). If this is the case, it is necessary to investigate to what extent the referent object is processed in ASD and how this differs in RJA and IJA. This is particularly pertinent considering the social deficits of ASD and models of joint attention that position JA as a social information processing and learning system.

The use of gaze contingent virtual characters is increasingly being adopted to understand social responses in ASD and typical development (Bernardini, Porayska-Pomsta & Smith, 2014; Jarrold et al., 2013; Mundy et al., 2016; Lahiri, Warren & Sakar, 2011; Rajendran, 2013) and these techniques demonstrate promise for a better understanding of both RJA and IJA (Courgeon et al., 2014; Kim & Mundy, 2012). Computer based, virtual environments are considered to be enjoyable and engaging for individuals with ASD because they are perceived as predictable, simple and unthreatening relative to real life person-to-person interactions (Rajendran, 2013). Gaze contingent virtual characters can also be preprogramed to respond to participants' gaze alterations (Courgeon et al., 2014; Schilbach et al. 2010, Pfeiffer et al. 2011; Trepagnier, Sebrechts, Finkelmeyer, & Ramloll, 2004). This type of technology allows for a more sophisticated insight into human interaction, which includes the production of social behaviour as well as the perception of social behaviour. Real time interactions with gaze contingent avatars are dependent on the participant’s input and coordination with the virtual character and real time feedback is provided. This avoids investigating people as passive observers of social stimuli and gives them a more active role that more realistically reflects expectations of a real life social interaction. These new techniques are therefore ideal for investigating both RJA and IJA. As such, the current thesis will use a gaze contingent virtual character to investigate the effects of responding to and initiating gaze shifts in a simulated joint attention scenario.

1.11 The current thesis

This thesis aims to expand our knowledge of joint attention mechanisms in individuals with ASD and typical development. It will focus on key components and behaviours needed for successful JA, specifically; reflexive and voluntary visual orienting to gaze cues, gaze following, initiating gaze shifts and how this affects attending and processing of the referent object. This will be explored in children with ASD, typically developing children and typically developing adults with varying levels of autistic traits. This aims to inform theoretical perspectives of joint attention to extend their scope beyond very early development to include how joint attention affects cognitive processing in childhood and adulthood, and to investigate the impact of autistic characteristics. Studying joint attention in school-aged children with and without ASD will allow us to investigate differences at a stage where clinical profiles are more established than in early years but nearer the initial appearance of ASD than for adult populations (Rice, Moriuchi, Jones & Klin, 2012). In light of recent studies demonstrating the effect of joint attention on adult's information processing (Bayliss et al., 2013; Edwards et al., 2015; Kim & Mundy, 2012; Marno, et al., 2014) and the evidence that autistic traits may attenuate these effects (Bayliss, DiPellegrino & Tipper, 2005; Edwards et al., 2015), further investigation into joint attention in the adult population will provide a greater understanding of its role in human cognitive development in both typical and ASD populations (Kim and Mundy, 2012). Establishing the effects of autistic traits on joint attention in the typically developing population will allow for more useful comparisons between typically developing and ASD populations in future joint attention research. Furthermore, comparing individuals with higher and lower levels of autistic traits will identify if gaze behaviour and subsequent information processing varies in the typical population and whether this can be linked to a more "autistic like" profile of characteristics. This is particularly useful for testing the notion of ASD as a continuum that extends beyond those with an autism diagnosis to the typically developing population (Baron-Cohen et al., 2001). Three studies measuring eye movements and cognitive processing during cueing and simulated joint visual attention tasks will be reported here.

The first study in this thesis will use gaze and arrow cueing tasks to investigate how social and non-social visual orienting is influenced by autistic traits. Previous studies have suggested that although the ability to orient to gaze cues seems to be intact in individuals with ASD, this may be atypical (Goldberg et al., 2008; Ristic et al., 2005; Senju et al., 2004; Vlamings et al., 2005). Individual differences in gaze cueing have also been demonstrated along the broader autism continuum in typically developing adults with varying levels of autistic traits (e.g. Bayliss, DiPellegrino and Tipper, 2005; Lasalle & Itier, 2015; Miu et al., 2012). Some researchers have described potential atypical strategies in ASD as ‘non-social’ whereby the social content of the gaze cue may be omitted (Goldberg et al., 2008; Ristic et al., 2005; Vlamings et al., 2005). Differences in responses to gaze and arrow cueing tasks between ASD and TD groups support this view (Stauder et al., 2011; Vlamings et al., 2005). Overall, the impact of autistic traits on gaze and arrow cueing remains unclear. The first study of this thesis therefore aims to investigate whether visual orienting to gaze and arrow cues is influenced by autistic traits. Eye tracking methods and pro and anti-saccade tasks will be used to test overt visual orienting to gaze and arrow cues in TD individuals with higher and lower levels of autistic traits. These methods are novel to this participant group and may be sensitive to more subtle differences that may not be detected by traditional covert orienting paradigms. A better knowledge of the extent of variation in the general population with high and low autistic traits is hoped to further delineate the mechanisms that are important to gaze following and how these may be associated with autistic characteristics.

The final two studies of this thesis aim to investigate how joint attention affects recognition memory for the referent object in children with and without ASD and adults with high and low levels of autistic traits. Previous studies have suggested that joint attention can facilitate object processing, including affective evaluations and recognition memory (Bayliss et al., 2006; Marno et al., 2014; Kim & Mundy, 2012; Striano et al., 2006). A recent gaze contingent joint attention paradigm has also suggested that facilitative effects of JA may be enhanced for IJA compared to RJA in typically developing adults and children (Kim & Mundy, 2015, Kim et al., 2015;

Mundy et al., 2016). This effect of enhanced memory in IJA has not been found in children with ASD (Mundy et al., 2016). Eye tracking evidence also suggests that individuals with ASD may not attend to gazed at objects for as long as typically developing individuals (Bedford et al., 2012; Falck-Ytter, Thorup & Bolte, 2015; Fletcher-Watson et al., 2009; Freeth et al., 2011; Riby et al., 2013). Attention towards and efficient processing of the referent object are important aspects of JA that likely contribute to subsequent processing, memory and learning. If individuals with ASD do not benefit as much from the facilitative effects of JA this may have a negative effect on their social cognition and information processing. It is therefore necessary to investigate to what extent the referent object is processed in ASD and how this differs in RJA and IJA. Until recently, experimental paradigms have focused mainly on the effects of RJA and there is a comparative lack of experimental research on IJA. It is therefore not yet clear how the cognitive effects of IJA and RJA may differ. Understanding any differential effects could help unpick any differences in the mechanisms for RJA and IJA and establish where individuals with ASD may be most impaired. Study 2 and 3 of this thesis will use a gaze contingent, computer based avatar to investigate joint attention interactions in children with and without ASD and adults with high and low levels of autistic traits. Participants' gaze as they respond to joint attention (RJA) and initiate joint attention (IJA) with the avatar will be measured and the effect of RJA and IJA on subsequent processing of the referent object will be explored. Investigating these elements of JA in typically developing individuals with high and low levels of autistic traits will be informative in our understanding of how RJA and IJA are processed along the broader autism continuum. This will determine any differential effects RJA and IJA may have on the cognitive processing of those with higher and lower levels of autistic traits. This aims to contribute to an understanding of how JA is associated with autistic symptoms. An individual's location on the broader autistic continuum (high/low/ASD diagnosis) is the outcome of development that has been constrained by autistic traits and characteristic (Mareschal et al., 2007). These traits have been suggested to affect some visual and attentional processes in typically developing individuals in a similar way as in autistic individuals. Examining how autistic traits affect joint attention behaviour in the typical population will therefore complement joint attention studies in ASD and allow for a better understanding about what shapes joint attention atypicalities and whether these may lie on a continuum. Alternatively, a specific pattern of JA effects found in individuals with ASD but not in those with higher levels of autistic traits could represent aspects of joint attention most severely impacted by ASD or that may be unique to ASD (Landry & Chouinard, 2016). Understanding how joint attention behaviours are affected by autistic traits will allow these associations and dissociations to be made. Overall, measuring social, cognitive and behavioural functioning in both typical and autistic populations is important in characterising the full behavioural and developmental trajectory of JA.

Chapter 2: Study 1, experiment 1.1

Gaze and arrow cueing in adults with higher and lower levels of autistic traits

2.1.1 Introduction

After years of using Posner style cueing tasks to investigate visual orienting in autism and typically developing populations, there is still no firm consensus on how individuals with ASD orient to gaze cues. Neither are there firm conclusions on whether visual orienting to social and non-social cues such as gaze and arrows differs in the typically developing population. Although evidence suggests individual differences in the visual domain related to autistic traits in the typically developing population, it is not yet clear how these traits could affect visual orienting to gaze and arrow cues. This must be further investigated to more fully explain visual orienting to both social and non-social cues in typical and atypical development. Explaining the mechanisms behind gaze cueing requires a more complete understanding of behavioural individual differences and better knowledge of the complex and interacting processes involved in attention to gaze and non-social cues. Furthermore, understanding any individual differences related to autistic traits that may occur in the typically developing population will test the continuum approach, complement the data from studies of individuals with ASD and help determine the variation in social orienting and its association with autistic characteristics.

Several instruments have been developed to measure traits consistent with the broader autism phenotype in the typically developing population (e.g. the Broader Autism Phenotype Questionnaire, Hurley et al., 2007; the Subthreshold Autism Trait

Questionnaire, Kanne et al., 2012; the Social Communication Questionnaire, Rutter, Bailey & Lord, 2003; and the Autism Spectrum Quotient, Baron-Cohen, et al, 2001). The most well-established and commonly used measure of autistic traits is the Autism Spectrum Quotient (AQ). The AQ is a questionnaire designed by Baron-Cohen and colleagues (2001) to measure the degree to which a typically developing adult possesses traits qualitatively similar to those that characterise ASD. It measures strengths and weaknesses in social and non-social domains associated with ASD. These domains include: communication, social skills, attention to detail, attention switching, and imagination (Baron-Cohen et al., 2001). Evidence of higher AQ scores in relatives (Constantino et al., 2006) and parents (Constantino & Todd, 2005; Wheelwright, Aeyung, Allison & Baron-Cohen, 2010) of children with ASD supports the use of the AQ to study the continuum approach of ASD. Furthermore, high AQ scores in typically developing population samples have been associated with similar performance on behavioural tasks found in ASD samples. For example, faster performance in embedded figures (Grinter et al., 2009), block design (Stewart et al., 2009) and visual search tasks has been found in typically developing individuals with higher AQ scores and individuals with ASD diagnoses. Performance on the 'mind in the eyes task' in the typically developing population has also been reported as inversely correlated with AQ score, suggesting weaker theory of mind in those with higher levels of autistic traits (Baron-Cohen, et al., 2001). Furthermore, higher AQ scores have been associated with diminished face inversion effects (Wyer, Martin, Pickup & McCrae, 2012), reduced reciprocity and social modulation of direct gaze (Chen & Yoon, 2011) and weaker gaze cueing effects (Bayliss, DiPellegrino & Tipper, 2005; Hudson, Nijboer & Jellema, 2012; Lasalle & Itier, 2015). Taken together, these findings suggest that the AQ may be associated with certain styles of social cognition, attention and behaviour expected across the broader autism continuum.

The current study aims to investigate gaze and arrow cueing in typically developing individuals with high and low levels of autistic traits. The cueing task from the Vlamings et al. (2005) study was adapted for this purpose and the AQ was used to differentiate participants with higher and lower levels of autistic traits. Vlamings et al., (2005) used a classic Posner style cueing paradigm where participants with and without ASD were presented with gaze and arrow cues and asked to detect a peripherally appearing target. They found that their group of typically developing adults responded more slowly to gaze cues than arrow cues. They also found lateralised cueing effects for gaze cues whereby significant congruency effects were apparent for rightward gaze cues but not leftward gaze cues. In contrast, no differences in reaction times were found between gaze and arrow cues in the ASD group, and asymmetrical cueing effects were found for arrow cues rather than gaze cues. This paradigm has also demonstrated these subtle differences in gaze cueing between children with and without ASD (Stauder, Bosch & Nuij, 2011) and parents of children with and without ASD (Scheeren & Stauder, 2008). This suggests that although orienting in response to gaze and arrow cues in ASD and the BAP is intact, it may be atypical. It is therefore worthwhile investigating whether differences in gaze and arrow cueing are detectable further along the continuum in individuals from the typically developing population and whether these are associated with autistic traits. To extend and improve on the Vlamings et al (2005) methodology, the current investigation will 1) use eye-tracking procedures to monitor and record participant's eye movements, 2) use pro and anti-saccade tasks, and 3) recruit participants from the typical population with high and low levels of autistic traits.

Eye tracking procedures will allow for richer data and a more precise measure of visual attention. This will uncover any differences in cueing for gaze and arrow cues and any seemingly 'non-social' patterns of gaze cueing previously suggested in ASD. This is with the aim to identify any existing attentional and socio-cognitive differences within the typical population with higher and lower autistic traits.

The use of pro and anti-saccade tasks in conjunction with a measurement of autistic traits is a novel contribution to gaze and arrow cueing research. Furthermore, eye-tracking methods allow for the spatial and temporal characteristics of saccades to be measured precisely and directly. This will allow us to quantify participants' reaction times and accuracy towards or away from the target and their ability to inhibit reflexive saccades in the direction of the cues. Here we aim to gain a unique insight into the processes behind gaze and arrow cueing and the effects of autistic characteristics. SRTs and erroneous saccades (i.e. saccades away from the target in the pro-saccade task and saccades towards the target in the anti-saccade task) will be recorded. It is hypothesised that participants with fewer autistic traits will demonstrate longer SRTs to the instructed location (towards the target for the pro-saccade task and to the opposite side of the screen for the anti-saccade task) when cued by gaze than by arrows. Conversely, individuals with higher levels of autistic traits are expected to show similar SRTs for both gaze and arrow cues in both tasks, reflecting very similar processing for both cues. Both groups are expected to show similar SRTs to arrow cues. There is also expected to be a general congruency effect for both groups with congruent cues eliciting faster responses than incongruent cues in both tasks. To further explore the laterality findings of Vlaming et al. (2005), we will also investigate the impact of target direction and cue location. In line with Vlamings et al. (2005), we expect to find lateralised and cue specific congruency effects, which may differ for each cue in those with lower and higher levels of autistic traits. Finally, individuals with low and high levels of autistic traits may differ in their errors made in each task. We predict that those with low levels of autistic traits will demonstrate increased errors for gaze cues than individuals with high levels of autistic traits. If these hypotheses are supported, this will support the theories and findings suggesting an association between attention to eye gaze, impaired social attention mechanisms and exhibited autistic traits.

2.1.2 Method

Participants

Participants were recruited from online community fora, the School of Psychological Sciences and Health's participant pool, and the general student population at the University of Strathclyde. For the first part of the recruitment process, participants were asked to complete an online version of the Autism Spectrum Quotient (AQ) questionnaire. One hundred and eighteen people completed the online questionnaire in full. The mean AQ score of all 118 online questionnaire respondents was 15.88 (SD = 9.67, range = 3-42).

Participants with the highest AQ scores (N=37, AQ score range = 22-42) and the lowest AQ scores (N=39, AQ score range = 3- 14) were initially contacted via email with an invitation to take part in the experimental task. This led to the recruitment of 21 participants who took part in the lab based experiment. The remaining questionnaire respondents with AQ scores between 15 and 21 were then also contacted with an invitation to take part in the experimental task. This led to the recruitment of a further 19 participants who took part in the lab based experiment.

A total of 40 participants took part in the lab based experimental task (aged between 18.33 years and 41.25 years old: 15 males with a mean age of 23.9 years old, SD = 5.8, and 25 females with a mean age of 24.1 years old, SD = 5.5). The overall mean AQ score was 15.2 (SD = 6.7). Participants were split into "high" and "low" scoring AQ groups using a median split. The median split method has commonly been used to split typically developing samples into those with relatively 'higher' or 'lower' levels of autistic traits (e.g. Chen & Yoon, 2011; Hudson, Nijboer & Jellema, 2012; McKenna, Glass, Rajendran & Corley, 2015; Zhao, Uono, Yoshimura & Toichi, 2015). While using a median split can lead to potential error and loss of power, this method was used here to allow for the comparison of two groups. The median AQ score was 16.5, participants scoring below this score were allocated to the "low AQ" group and those scoring above were allocated to the "high AQ" group. Figure 2.1 shows a frequency histogram of participant AQ scores, this demonstrates a clear dip in the centre and provides some support for the median as an appropriate cut-off to separate the two experimental groups. Table 2.1 shows the participant characteristics for each group. Mean AQ scores here are comparable to those from previous studies comparing high and low AQ groups (e.g. Mckenna et al., 2015).

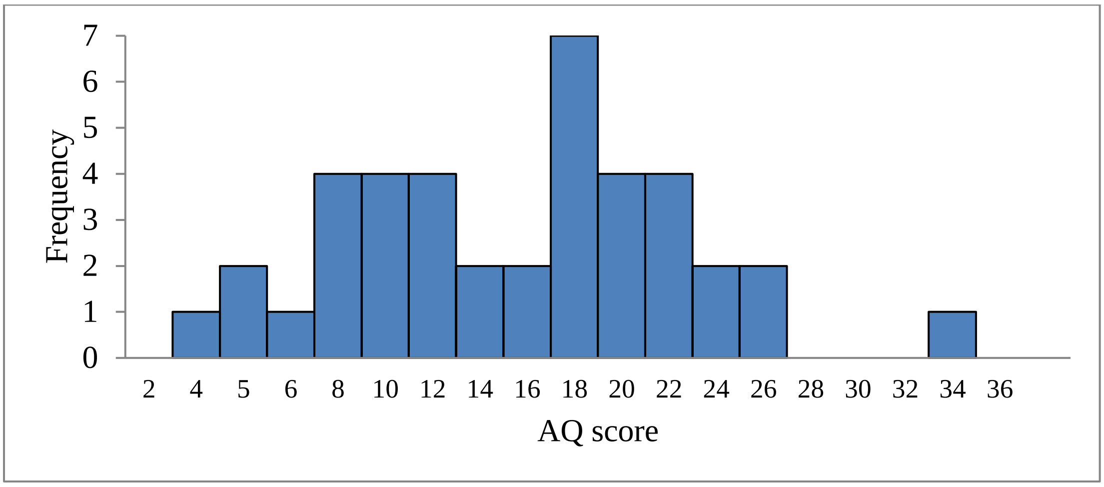

Figure 2.1. Frequency histogram of participant AQ score, experiment 1.1.

Table 2.1.

Participant characteristics, experiment 1.1

AQ group	Mean AQ score (SD)	Mean age in yrs (SD)	Sex, M/F
Low	9.6 (3.5)	23.6 (5.1)	6/14
High	20.8 (3.9)	24.6 (5.9)	9/11

Participants from the participant pool who took part in the lab based experiment received course credits for taking part. Those who were not eligible to receive course credit for participation received a £5 high street shopping voucher. All participants had normal or corrected to normal vision with no neurological impairments and all provided written informed consent.

The Autism Spectrum Quotient

The Autism Spectrum Quotient (AQ) was used to measure participants' autistic traits. The questionnaire contains 50 self-statements covering five subscales associated with clinical features of ASD. The subscales include: communication, social skills, attention to detail, attention switching, and imagination. Each subscale comprises 10 items and each item is responded to on a 4 point Likert scale with the options of “definitely agree”, “slightly agree”, “slightly disagree” or “definitely disagree”. The items are counterbalanced with an affirmative response corresponding to autistic like traits for half of the items (e.g. When I’m reading a story, I find it difficult to work out the characters’ intentions). AQ questionnaires were scored out of 50 using the binary scoring method proposed by the developers, whereby participants either score 1 or 0 points per item (Baron-Cohen et al., 2001). Higher AQ scores reflect higher levels of autistic traits.

The AQ was originally validated on a sample of individuals with Asperger syndrome or high functioning autism, high achievers in mathematics, university students in science and non-science subjects and non-students from the typically developing population (Baron-Cohen et al., 2001). This study showed the AQ to have good test-retest reliability. Total AQ scores and scores within the five subscales were also normally distributed, with moderate to good internal consistency for each of the subscales and good internal reliability overall. Further studies have confirmed the good test-retest reliability and overall internal consistency of the AQ (e.g. Austin, 2005; Hoekstra et al., 2008; Kurita, Koyama, & Osada, 2005). Although not developed as a diagnostic measure, the AQ has also demonstrated sensitivity and specificity when used in a clinical sample (Austin, 2005; Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). As such it has been suggested for use as a screening tool for the general population with a threshold score of 26 and above suggesting Asperger syndrome (Woodbury-Smith et al., 2005) and 32 and above being described as “clinically significant” (Baron-Cohen et al., 2001). The AQ has also been translated into different languages and is reliable in Japanese (Kunihira et al., 2006; Kurita et al., 2005; Wakabayashi, Baron-Cohen, Wheelwright & Tojo, 2006), Dutch (Hoekestra et al., 2008) and Austrian (Voracek & Dressler, 2006) populations. Although reliability and internal consistency for the AQ *overall* has consistently been reported as adequate to high (e.g. Austin, 2005, Hoekstra et al., 2008; Ingersol, Hopwood, Wainer & Donnellan, 2011; Stewart & Austin, 2009) some studies have reported moderate to low internal consistency for the separate subscales of the AQ (e.g. Austin, 2005; Freeth, Bullock & Milne, 2013). As such, the factor structure has been contested. Five (Baron-Cohen et al., 2001; Ingersol et al., 2011), four (Stewart & Austin, 2009), three (Austin, 2005) and two factor solutions (Hoekstra et al., 2008) have been proposed. Although the BAP-Q (Hurley et al., 2007), the SRS (Ingersol et al. 2011) and the SATQ (Nishiyama et al., 2014) have been recommended over the AQ, these measures have not been as widely used nor as thoroughly tested as the AQ. Despite its potential drawbacks, the AQ is the most well established, commonly used and efficient to administer measure of autistic traits in the general population.

Apparatus

The experiment was created and run on experiment builder software (SR research Ltd, Ontario, Canada) and presented on a 19” monitor with 1280x1024 pixel resolution and 85HZ refresh rate. Eye movements were recorded at 1000HZ with a spatial resolution of 0.01° using an eye link 1000 eye tracker. Pupil position was defined as the centre of the pupil and saccade onset was defined as a change in pupil position with a minimum velocity of 22° per second and a minimum acceleration of 8000° per second.

Visual stimuli

The visual display had a black background with a small grey fixation point (4 pixels x 4 pixels) in the centre. The face stimuli presented were colour face images from the Radboud faces database (Langner et al., 2010). The background, neck and shoulders were edited out of the original photographs and replaced with a uniform black background. There were 60 different face images in total, portraying 20 unique characters, 10 male and 10 female. All faces were shown with their eyes gazing straight ahead during the non-directional gaze cue and to the left and right during the directional gaze cues. The faces measured approximately 11.3 ° in width by 18.7 ° in length. The size of the eyes was held constant across the images at 2.3 ° in width and 2.6 ° in length. In the arrows task, the non-directional cue consisted of two arrows pointing to both sides of the visual field (< >), and to the left (<<) or the right (>>) for the directional cues. The arrows were white and measured 4.3 ° in width and 1.6 ° in height. All cues were presented in the centre of the screen. The target was a white letter "A" measuring 1.4 ° wide and 1.6° high. This was presented 10.6° to the left or right of the fixation point. Examples of the visual stimuli can be seen in figure 2.2.

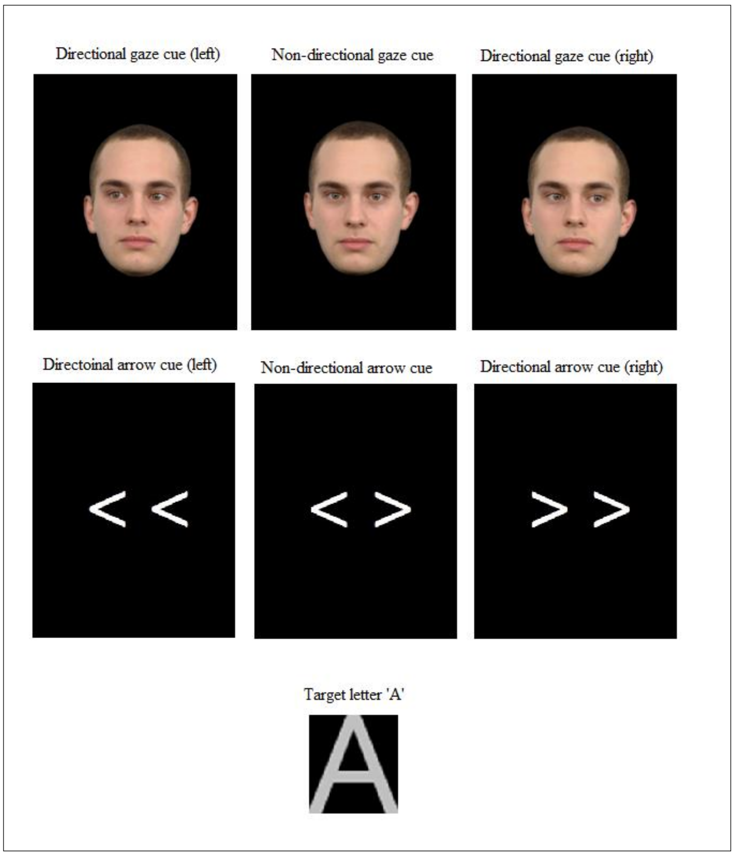

Figure 2.2. Examples of the visual stimuli, experiment 1.1

Experimental Tasks

Participants completed two cueing tasks, a pro-saccade task and an anti-saccade task. In the pro-saccade task, participants were instructed to look at a target letter ‘A’ when it appeared. In the anti-saccade task participants were instructed to look away from the target upon its appearance, towards the opposite side of the screen. These tasks included two cue type conditions, eye gaze cues and arrow cues. To begin both tasks, a fixation point was presented, followed by a non-directional cue for 500ms, then a directional cue for 400ms. This was immediately followed by the appearance of the target letter ‘A’ on the left or right side of the screen. Figure 2.3 shows an example of the order and time course of the stimuli presentation. The directional cues indicated the target location either correctly (congruent trial) or incorrectly (incongruent trial). The gaze cue and arrow cue conditions were conducted separately, as were the pro and anti-saccade tasks. Two blocks of 80 trials were completed for both cue conditions for both the pro and anti-saccade tasks. This amounted to 640 trials in the study in total. The order of task and stimulus presentation for each of the trial blocks was fully counterbalanced and randomised.

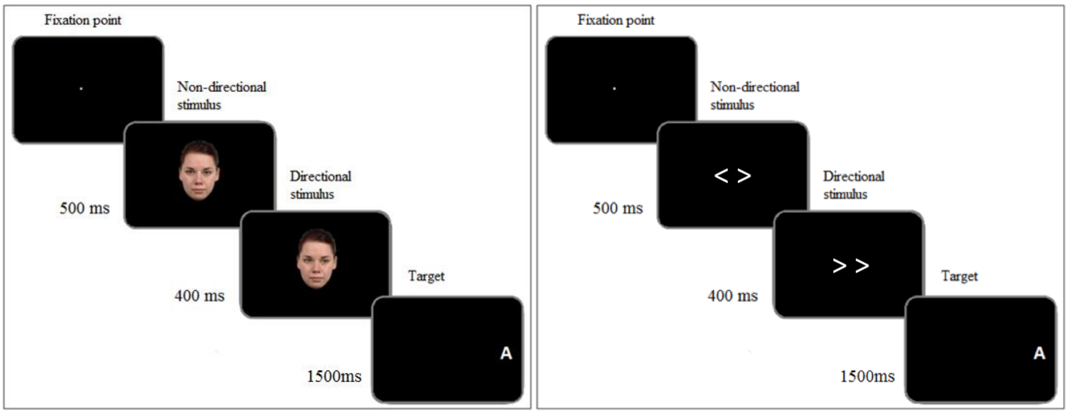

Figure 2.3. Order and time course of stimuli presentation, experiment 1.1

Procedure

To begin the lab based task, participants completed Miles' (1930) test of eye dominance. This involved the participant extending both arms and placing their hands together to form a triangular opening they could see through. The participant then observed a distant point on the wall through the opening and alternated closing their left and right eyes. Ocular dominance was determined as the eye that was open when the observed point remained in view. Only the participant's dominant eye was tracked for the duration of the tasks. The experiment took place in a quiet laboratory with participants seated with their chins and foreheads on a headrest to prevent head movements. The chinrest was positioned 57 centimetres from the computer screen. Instructions explaining the task were given to the participant. The experimenter went over the instructions with the participants to ensure understanding. Participants were explicitly told that the cues were not predictive of the target location. Participants were asked to maintain central fixation until target presentation and respond as quickly and as accurately as possible. They were also advised not to anticipate or guess which side the target would appear on. Following standard nine point calibration, validation and drift correct procedures, each trial began when participants' had successfully fixated on the central fixation point. Participants were given breaks between trial blocks with their eye movements re-calibrated before the beginning of each new block. When participants had finished all of the experimental trials they were thanked and provided with a debrief sheet. The experimental trials took approximately 45 minutes to complete.

2.1.3 Results

Eye movement data

The eye movements considered for analysis were the first saccades made by participants after the onset of the target. Any trials where the participant failed to respond were removed from the analysis. Trials were also excluded if participants' first saccade anticipated the target's appearance or their response was delayed. Anticipatory saccades were defined as saccades beginning up to 80ms after the target onset and delayed responses were defined as saccades beginning up to 699ms after the target onset (Fischer, Gezeck & Hartnegg, 1997). Saccades with amplitude of less than 1° were also removed from the analysis. Furthermore, all saccades improperly fixated at the time of target onset were removed from the analysis. Although participants were asked to maintain central fixation throughout the tasks until the target appeared, their eyes often moved outwith 1° of the central point of the screen between the presentation of the initial fixation point and the target onset. This occurred more in the face trials than the arrow trials and may have been due to the disappearance of the central fixation point when the non-directional stimulus was presented. The improper fixation criterion was therefore expanded with improper fixation defined as a saccade that began outside 3.3° from the centre of the screen instead of 1°. This area, represented the average distance between the centre of the screen and the outer canthus across the face images, this is represented in figure 2.4. This area was also used to eliminate improper fixations in the arrow trials. This included the removal of 11.43% of all gaze trials (11.50% from the anti-saccade task and 11.35% from the pro-saccade task) and 7.86% of all arrow trials (7.03% from the anti-saccade task and 8.69% from the pro-saccade task). In total, these exclusions lead to 9.7% of all trials being removed from the analysis.

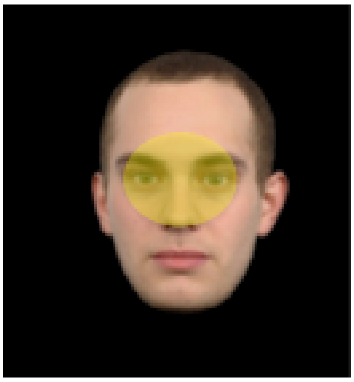

Figure 2.4. Example of fixation area, experiment 1.1

The saccadic reaction time (SRT) of the participant’s first saccade either towards or away from the target was calculated. An average SRT was calculated for each participant for each task (pro-saccade and anti-saccade), cue type (gaze and arrow cue), cue direction (left cue and right cue) and target location (left and right) condition. Only correctly directed saccades were considered for the SRT analyses. The total number of erroneous saccades for each task (pro-saccade and anti-saccade), cue type (gaze and arrow cue), cue direction (left cue and right cue) and target location (left and right) were also calculated and divided by the total number of trials per participant to generate an overall error rate for each participant per condition. Before statistical analysis, the data were inspected for any abnormalities and outliers. Shapiro-Wilk tests and calculations of z-skewness were also used to check the normality of the data and transformations were conducted where necessary. Initial screening revealed skew in some experimental conditions that was not eliminated by transformations. Parametric tests are considered to be robust to violations of the assumption of normal distribution (e.g. Clark-Carter, 1997) so parametric analyses are reported here to allow interaction effects to be investigated. However, precautionary nonparametric tests were also conducted. Results of the non-parametric analyses were consistent with the reported results of the parametric tests. SRTs and error rates for the pro-saccade and anti-saccade tasks were analysed separately. Follow up tests for significant interaction effects between cue direction and target location are not reported here. All of these interactions indicated congruency effects whereby congruent cues were responded to more quickly and with fewer errors than incongruent cues. Follow up tests of significant interactions are only reported if they involved the AQ group or cue type variable or were unique to either group or cue.

Pro-saccade task, SRT analysis

Table 2.2 shows the mean SRTs for gaze and arrow cues in the pro-saccade task for congruent cues, incongruent cues and each cue direction and target location condition. Here, one participant from each group was identified as an outlier in one condition cell (z-score >3.29). These scores were replaced with the mean plus two standard deviations (Field, 2008). SRT data for both the low and high AQ groups also showed evidence of positive skew and non-normal distribution. Log and square root transformations of the data did not eliminate the skew so the original data were used for analysis.

To compare the SRTs between the groups with higher and lower autistic traits, a 2 (group, high/low autistic traits) × 2 (cue type, gaze/arrow) × 2 (cue direction, left/right) × 2 (target location, left/right) mixed ANOVA was conducted. AQ group was the between-group factor and cue type, cue direction and target location were within-groups factors. For the pro-saccade task, the ANOVA showed no main effect of AQ group ($F(1,38) = .017$, $p = .895$), there was also no main effect of cue direction ($F(1,38) = 2.04$, $p = .161$) or target location ($F(1,38) = 3.14$, $p = .084$). There was a main effect of cue type ($F(1,38) = 20.76$, $p < .001$, $\eta_p^2 = .35$) with arrow cues (M = 168, SD = 33.24) eliciting faster SRTs than gaze cues (M = 182, SD = 41.19). There was a significant interaction between cue direction and target location ($F(1,38) = 24.75$, $p < .001$, $\eta_p^2 = .39$) reflecting the expected congruency effects. The interaction between cue direction and AQ group approached but did not reach significance ($F(1,38) = 4.00$, $p = .053$, $\eta_p^2 = .10$). No other interactions reached significance (all $F \leq 2.22$, $p \geq .921$, $\eta_p^2 \leq .06$).

Pro-saccade task error rate analysis

Two participants from the low AQ group and three from the high AQ group were identified as outliers in one or more condition cells (z-score >3.29). These scores were replaced with the mean minus two standard deviations (Field, 2008). The mean error rates from the pro-saccade task are displayed in table 2.3. The error rate data were also positively skewed. This was due to overall ceiling level performance in more than one condition. Due to the ceiling level performance, an ANOVA was not conducted for all conditions in this task. The variables 'cue direction' and 'target location' were instead collapsed into a single 'congruency' (congruent/incongruent) variable. This data were also positively skewed. Transformations did not reduce the skew so the original data were used for analysis.

A 2 (group, high/low autistic traits) × 2 (cue type, arrows/gaze) × 2 (congruency, congruent/incongruent) mixed ANOVA revealed no significant main effect of group ($F(1,38) = 1.41$, $p = .243$) or cue type ($F(1,38) = .024$, $p = .878$). Although incongruent cues appeared to elicit more errors than the congruent cues this effect was not significant ($F(1,38) = 2.89$, $p = .098$). Furthermore, no interactions were significant (all $F \leq .913$, $p \geq .345$, $\eta_p^2 \leq .02$).

Overall, analysis of the pro-saccade SRT data for experiment 1.1 revealed the expected validity effects for both gaze and arrow cues whereby responses were faster when the cue correctly indicated the target location. Furthermore, gaze cues were found to elicit significantly slower oculomotor responses than arrow cues. Congruency and cue type did not affect error rates for this task. This may be due to the limited number of overall errors made and ceiling level performance from several participants.

Table 2.2.

Mean SRTs, pro-saccade task, experiment 1.1

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	183 (36.48)	175 (36.10)	192 (37.79)	183 (45.98)	189 (39.28)	167 (31.37)	196 (43.81)
High	180 (46.51)	177 (50.09)	181 (40.97)	178 (51.21)	183 (47.15)	177 (52.04)	183 (45.98)
	Arrow Cues						
Low	168 (31.92)	162 (31.94)	174 (33.71)	166 (39.71)	173 (31.26)	157 (26.41)	174 (38.08)
High	168 (35.34)	162 (30.29)	174 (42.08)	164 (32.89)	171 (40.84)	161 (30.57)	177 (46.20)

Table 2.3.

Mean error rates, pro-saccade task, experiment 1.1

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	.008 (.018)	.003 (.009)	.012 (.035)	0.00 (0.00)	.017 (.045)	.005 (.017)	.008 (.026)
High	.005 (.008)	.004 (.010)	.005 (.013)	0.00 (0.00)	.009 (.023)	.009 (.022)	.002 (.007)
	Arrow Cues						
Low	.009 (.019)	.003 (.009)	.015 (.034)	0.00 (0.00)	.022 (.053)	.005 (.014)	.007 (.023)
High	.003 (.006)	.001 (.002)	.005 (.011)	.001 (.004)	.008 (.020)	0.00 (0.00)	.001 (.004)

Anti-saccade task, SRT analysis

Data analysis for the anti-saccade task followed the same procedure as the pro-saccade analysis. Firstly, one outlier was removed from the low AQ group as this participant performed at below chance level for the gaze cue condition (> 50% errors). SRT data from the low AQ group showed signs of positive skew. Square root transformations completely eliminated this skew and the transformed data demonstrated a normal distribution. The transformed data were therefore used for the following analysis. The data for congruent leftward gaze cues showed unequal variance ($F(1,37) = 9.65$, $p = .004$). Levene's test remained significant when the data were untransformed ($p = .002$) and log transformed ($p = .005$). ANOVA is considered to be robust to moderate departures from the homogeneity of variance assumption therefore the square root transformed data were still used for analysis but should be interpreted with caution as the sample size between groups is unequal (high AQ N = 20, low AQ N = 19). Table 2.4 shows the mean SRTs for gaze and arrow cues for the anti-saccade task for congruent cues, incongruent cues, and each cue direction and target location condition.

Table 2.4.

Mean SRTs for anti-saccade task, experiment 1.1

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	229 (32.68)	224 (31.32)	236 (36.55)	222 (29.79)	233 (40.68)	226 (38.60)	241 (33.92)
High	253 (47.61)	250 (48.15)	258 (49.20)	253 (51.51)	251 (48.24)	247 (46.35)	262 (52.25)
	Arrow Cues						
Low	223 (36.13)	215 (34.32)	233 (39.92)	213 (26.39)	234 (44.89)	218 (45.09)	232 (38.38)
High	246 (39.86)	240 (36.17)	253 (45.40)	240 (38.64)	249 (47.36)	240 (39.94)	256 (49.20)

Table 2.5.

Mean error rates for anti-saccade task, experiment 1.1

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	0.22 (0.10)	0.19 (0.14)	0.26 (0.14)	0.18 (0.17)	0.27 (0.20)	0.18 (0.16)	0.25 (0.14)
High	0.20 (0.13)	0.15 (0.11)	0.26 (0.17)	0.11 (0.08)	0.31 (0.23)	0.20 (0.19)	0.21 (0.18)
	Arrow Cues						
Low	0.18 (0.12)	0.11 (0.13)	0.27 (0.17)	0.10 (0.11)	0.30 (0.21)	0.12 (0.17)	0.23 (0.18)
High	0.16 (0.11)	0.10 (0.09)	0.22 (0.15)	0.07 (0.08)	0.24 (0.21)	0.12 (0.13)	0.19 (0.12)

The ANOVA showed no main effect of AQ group, ($F(1,37) = 3.16$, $p = .084$) or target location ($F(1,37) = .696$, $p = .410$). There was a main effect of cue type ($F(1,37) = 5.69$, $p = .022$, $\eta_p^2 = .13$), with SRTs for gaze cues being slower (M = 242, SD = 42.31) than SRTs for arrow cues (M = 235, SD = 39.41). There was also a main effect of cue direction ($F(1,37) = 5.10$, $p = .030$, $\eta_p^2 = .12$) whereby leftward cues (M = 237, SD = 39.41) elicited faster SRTs than rightward cues (M = 240, SD = 40.96). Again, there was a significant interaction between cue direction and target location ($F(1,37) = 31.10$, $p < .001$, $\eta_p^2 =.46$) reflecting the expected congruency effects. No other interactions were significant (all $F \leq 1.96$, $p \geq .179$, $\eta_p^2 \leq .05$).

Anti-saccade error rate data analysis

The anti-saccade error rate data showed evidence of positive skew and non-normal distribution. Log and square root transformation did not eliminate the skew so the original data were used to conduct the analysis for the error rates.

Table 2.5 shows the mean error rates for gaze and arrow cues for the anti-saccade task. To compare the error rates between the groups, a 2 (group, high/low autistic traits) × 2 (cue type, gaze/arrow cues) × 2 (cue direction, left/right) × 2 (target location, left/right) mixed ANOVA was conducted. AQ group was the between-group factor and cue type, cue direction and target location were within-groups factors. The ANOVA suggested no significant main effect of AQ group, ($F(1,37) = 3.16$, $p = .085$). There was a significant main effect of cue type, ($F(1,37) = 6.49$, $p = .015$, $\eta_p^2 = .15$) and target location ($F(1,37) = 8.77$, $p = .005$, $\eta_p^2 = .19$) with more errors occurring for gaze cues (M = 0.21, SD = 0.12) than arrow cues (M = 0.17, SD = 0.12) and right targets (M = 0.22, SD = 0.14) than left targets (M = 0.17, SD =0.09) respectively. There was also a significant interaction between cue direction and target location ($F(1,37) = 38.92$, $p < .001$, $\eta_p^2 = .51$), reflecting the expected congruency effects. No other interactions were significant (all $F \leq 2.53$, $p \geq .120$, $\eta_p^2 \leq .51$).

Overall, analysis of the anti-saccade SRT data revealed that regardless of the cue type, saccades away from the target were faster when the cue correctly indicated the target location. Gaze cues were again found to elicit significantly slower oculomotor responses than arrow cues. Leftward cues were also found to elicit faster responses than rightward cues. Analysis of the error rates also revealed a significantly higher number of errors for gaze cues than arrow cues. Targets appearing on the right also elicited more errors than targets appearing on the left.

2.1.4 Discussion

The aim of this study was to investigate saccadic responses of participants with higher and lower levels of autistic traits in pro and anti-saccade tasks with non-predictive gaze and arrow cues. SRTs towards and away from the targets and error rates were calculated and analysed. Consistent with the notion that ASD is a spectrum disorder with traits and cognitive and behavioural styles which can extend to TD individuals high in autistic traits, this study examined whether individual differences in autistic traits impacted gaze and arrow cueing and whether the ‘non-social’ style of orienting suggested in ASD exists in the typical population high in autistic traits. Overall, the results of experiment 1.1 revealed no differences between the groups with higher and lower self-reported autistic traits in the pro-saccade or anti-saccade tasks. This suggests that overt visual orienting responses to non-predictive social and non-social cues do not differ as a function of autistic traits in the typical population. This is contrary to the findings of Bayliss and colleagues who have found differences between high and low autistic trait groups in covert attention cueing paradigms. Bayliss, DiPellegrino & Tipper (2005) found a correlation suggesting weaker gaze cueing in their group with high levels of autistic traits and no correlation for arrow cues. This may have been due to variability in AQ scores from the Bayliss, DiPellegrino & Tipper (2005) study and the current study. However, only the means for the male and female respondents from their studies are reported (Both studies had 5 male and 20 female participants. Study 1- males average AQ score: 18.9, females average AQ score: 17.2. Study 2- males average AQ score: 17.2, females average AQ score: 15.5). These are slightly higher than the means for the male and female participants in the current study (with mean AQ scores of 15.8 & 14.8 respectively). Nevertheless, the average scores for the high and low AQ groups in the current study were 20.8 and 9.6 respectively. This is close to the AQ scores reported for the high and low groups in Bayliss and Tipper's (2005) studies (study 1- High AQ group score: 21.2, low AQ group score: 10.3. Study 2- high AQ group score: 21.9, low AQ group score: 10.4). Here, Bayliss & Tipper (2005) found differences in orienting styles towards scrambled and unscrambled targets of faces and tools in their high and low AQ groups, however, similarly to the current findings, Bayliss and Tipper (2005) found no differences between the groups for gaze and arrow cues.

The lack of group differences in the current study is also in contrast with the findings of Lasalle & Itier (2015) & Miu et al. (2012) who found different gaze cueing effects for individuals with high and low autistic traits. This could be due to the emotional face stimuli used in their studies. Lasalle & Itier (2015) demonstrated weaker cueing effects for happy faces but not fearful faces in the high AQ group whereas Miu et al. (2012) found slower orienting to fearful faces in the higher AQ group. This may be due to the neutral face condition included by Miu et al. (2012). Fearful face stimuli have been show to elicit faster gaze orienting than neutral faces (Bayliss et al., 2011; Fox, Matthews, Calder & Yiend, 2007, Neath, Nilsen, Gittsovich, & Itier, 2013). Furthermore, individuals with ASD may not show the same attentional biases for fearful faces as TD individuals (Ashwin et al., 2007; Uono, Sato & Toichi 2009). Surprised and angry facial expressions can also elicit faster cueing responses (Baylees et al., 2011; Lasalle & Itier, 2015; Neath et al., 2013). It is so far unclear how various emotional facial expressions may interact with gaze cueing, various SOAs and autistic traits in the general population. Miu et al. (2012) also found that their participants with higher autistic traits were significantly slower to respond to the 'reading the mind in the eyes' task (Baron-Cohen et al., 1997). Although they did not find any differences in accuracy between the high and low group in this task, poorer performance has previously been found to correlate with higher scores on the AQ in the TD population (Baron-Cohen et al., 2001). Poorer emotion perception and atypical social orienting may have interacted to contribute to Lasalle & Itier (2015) and Miu et al.'s (2012) findings. Taken together, the results of this study and previous studies suggest that tasks manipulating the target context and including more complicated emotional stimuli, requiring emotional processing or theory of mind, may be needed to detect differences between typically developing high and low AQ groups.

The current study found that in the pro-saccade task, both gaze and arrow cues elicited faster orienting when they correctly indicated the target location rather than the opposite direction. This reflects the commonly found validity effect (Driver, 1999; Langton & Bruce, 2000) and suggests that the task manipulation was successful. Significantly faster SRTs for congruent cues were also found in the anti-saccade task. Taken together, the congruency findings suggest that in the pro-saccade task participants prepared a response in the same direction as the cues but in the anti-saccade task participants prepared a response in the opposite direction of the cues. This is consistent with Koval et al. (2005) and Gregory and Hodgeson's (2012) findings with gaze cues and contradicts the gaze imitation hypothesis that, on perception, gaze is followed automatically. However, here congruency effects did not interact with cue type, indicating that the congruency effects were similar regardless of the social nature of the cue. This is contrary to Gregory & Hodgeson's (2012) finding that congruent gaze cues but not arrow cues facilitated faster responses in the anti-saccade task. Their findings suggest that social, biological cues (gaze and finger pointing) preferentially influence speeded saccadic responses, supporting the notion that gaze is a unique cue which acts more automatically on the attentional and saccadic system. The SRT findings from the current study do not support this view and instead demonstrate that gaze cues and arrow cues elicit similar congruency and cueing SRTs. The cue stimuli used in these studies differed, with Gregory and Hodgeson (2012) using traffic sign style arrows and cropped photographic images of the eye area. However, this may not explain the differences in findings. Arguably a cropped image of the eyes is less ecologically valid than the full-face stimuli used in the current study as in reality we are less likely to view a pair of eyes outwith of the context of a face. It would be expected that more ecologically valid gaze stimuli may increase the social salience and evoke greater differences between the cues but this was not the case. Nonetheless, their finding was consistent across three different SOAs (100, 300 & 800ms) suggesting it is robust. However, Gregory and Hodgeson (2012) also included neutral cues in their experiment (eyes closed and arrows presented in a circle as in the UK road sign for a roundabout). It was only when the neutral cues were removed from the analysis that differences in congruency were found. Unexpectedly, the neutral cues elicited the longest SRTs so were deemed to be too engaging. When neutral cues were included in the analysis there was a significant interaction between SOA and cue type, with the differences between gaze and arrows approaching significance only at the shortest SOA. The use of a shorter SOA than the 400ms used in the current study may therefore elicit greater differences in congruency effects between the cues.

No interesting differences in laterality effects were discovered between the AQ groups. However, in the anti-saccade task, leftward cues were responded to more quickly than rightward cues, and higher error rates were evident for targets appearing on the right. In both pro and anti-saccade tasks, arrow cues were found to elicit faster oculomotor response times than gaze cues. This is in line with several findings from covert-orienting paradigms showing that gaze cues are responded to more slowly than arrow cues (Jonides, 1981; Driver, 1999; Friesen, Ristic & Kingstone, 2004; Vlamings et al., 2005). This suggests that gaze cues may take further processing than arrow cues. This finding may reflect the fact that face stimuli are more complex than arrow stimuli. However, in voluntary saccade tasks Kuhn and colleagues (2007, 2009, 2010) have consistently found similar visual orienting when a task instruction stimulus is paired with distracting gaze and arrow cues. This may be due to the sparse and schematic gaze cue stimuli used in these studies that may allow the cues to be viewed in a non-social way.

Error rate analysis for the pro-saccade task revealed no significant main effect of congruency. This is consistent with Koval et al.'s (2005) findings and may have been due to the limited number of errors made for this task generally. The pro-saccade task may also have been relatively simple for participants and was evidently easier than the anti-saccade task. Analysis of anti-saccade error rates revealed that significantly more errors were made for incongruent cues than congruent cues, again suggesting that participants tended to prepare a response in the opposite direction of the cue for optimum performance on the anti-saccade task. However, gaze cues elicited significantly more errors here than arrow cues. Errors are thought to be reflexive responses (Everling & Fischer, 1998). This suggests that compared with an arrow cue, the appearance of a gaze cue may elicit a more reflexive saccadic response, but one that is in line with the experimental task demands. In this case, a saccade away from gaze direction incurred errors on incongruent trials. Although they did not find any significant differences in erroneous saccades between gaze and arrow cues, the error rate data here is in agreement with Gregory and Hodgeson's (2012) conclusions that gaze cues may have privileged access to the oculomotor system over non-social cues; however, this seems to be task dependent. Furthermore, no differences in error rates were found between the AQ groups for either task. Previous studies using anti-saccade tasks to investigate oculomotor control in ASD populations have found that individuals with ASD make more errors in anti-saccade tasks than TD controls (Goldberg et al., 2002; Luna, Doll, Hegedus, Minshew, & Sweeney, 2007; Minshew, Luna & Sweeney,1999). No increase in errors for the group high in autistic traits was found in this study suggesting this may be a cognitive style specific to individuals (or subgroup(s) of individuals) with ASD.

Overall, this study suggests that gaze and arrow cues can direct attention in a voluntary and task dependent way, adapted for the task instructions of either pro or anti-saccade tasks. Here, autistic traits did not affect SRTs or the number of errors for the cueing task. One major limitation of this study is the lack of strict 'improper fixation' criteria. Although participants were instructed to maintain central fixation until the appearance of the target, the fixation point was removed at the appearance of the cue. Combined with the preceding non-directional cue, this potentially allowed participants eyes to drift considerably from centre. This was a particular problem in the gaze cue condition and meant that the improper fixation criterion, usually set at 1 degree from central fixation, had to be relaxed considerably to include the whole area around the eye. Although breaking from central fixation to explore the face reflects how people view faces, this did not allow for maximum control over eye movements. In order to ensure maximum control of eye movements another cueing study was conducted. The pro and anti-saccade task by Koval, Thomas and Everling (2005) was adapted for a follow up experiment.

Chapter 2: Study 1, experiment 1.2

2.2.1 Introduction

Experiment 1.2 included several changes to the stimuli and presentation of experiment 1.1. These changes were influenced by Koval et al.'s (2005) study. The current study aimed to expand on their findings by including a non-social, arrow cue.

This included the removal of the non-directional stimulus and the presentation of a fixation point until target presentation, in order to reduce the number of improper fixations. Additionally, to make the gaze and arrow cues more visually equivalent, but without minimising the ecological validity of the gaze cues, full, photographic face cues were still presented. These were however, reduced in size and grey-scaled. A shorter SOA of 200ms was also used, as used by Koval et al (2005) in order to elicit stronger cue and congruency effects as suggested by the persistent congruency effects for social cues at the shorter SOA (100ms) in Gregory and Hodgeson's (2012) anti-saccade task. Shorter SOAs have also been suggested to elicit greater cueing differences between groups with and without ASD (Landry & Parker, 2013).

2.2.2 Method

Participants

The participant recruitment process and exclusion criteria were as described for experiment 1.1. One hundred and forty eight people completed the online AQ questionnaire in full. The mean AQ score of all online questionnaire respondents was 15.08 (SD = 8.18, range = 4-36). Participants with the highest scores (N=51, range = 19 - 36) and the lowest scores (N= 48, range = 4 - 13) on the questionnaire were initially invited to take part in the experimental task. This led to the recruitment of 40 participants who took part in the lab based experiment. Remaining respondents with AQ scores of 14, 15, 17 and 18 were then also contacted, 8 replied agreeing to take part in the in the lab experiment.

A total of 48 participants who did not take part in experiment 1.1 took part in the lab based experimental tasks (17 males with a mean age of 25.4 years old, SD =

10.6. 31 females with a mean age of 23.3 years old, SD = 5.1). The overall mean AQ score was 18.7 (SD= 8.5). Participants were split into “high” and “low” scoring AQ groups using a median split. The median AQ score was 17, participants scoring below this score were allocated to the “low” group and those scoring above were allocated to the “high” group. Figure 2.5 shows a frequency histogram for the participant AQ scores. This demonstrates a very clear peak at the lower scores, below the median score of 17 for the lower AQ group and another peak for the higher AQ group at the AQ score of 28. This again provides some support for the use of the median split method. Table 2.6 shows the participant characteristics for both groups.

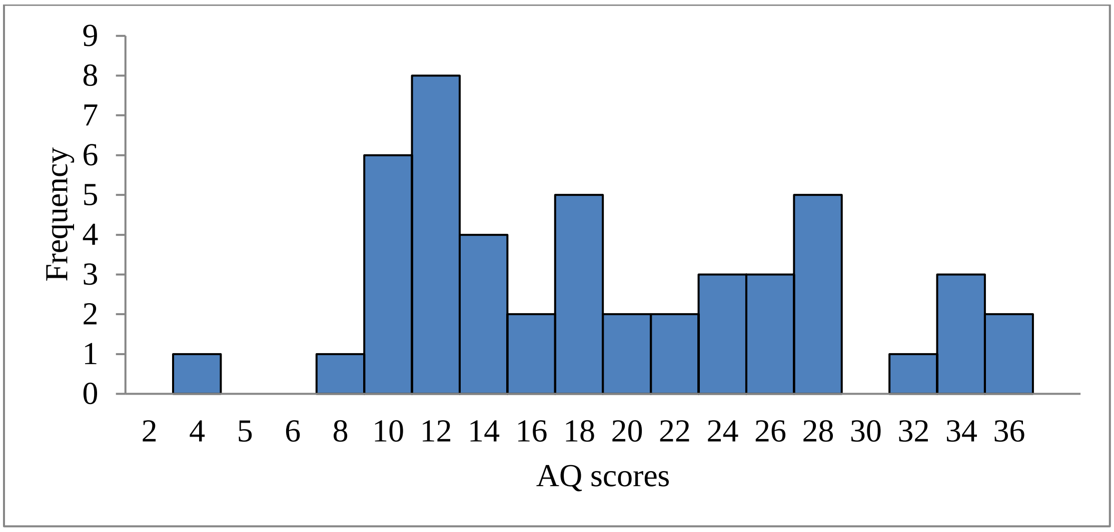

Figure 2.5. Frequency histogram of participant AQ scores, experiment 1.2

Table 2.6.

Participant characteristics, experiment 1.2

AQ group	Mean AQ score (SD)	Mean age in yrs (SD)	Sex, M/F
Low	11.04 (2.6)	26.1 (9.8)	6/16
High	25.2 (6.1)	22.4 (4.1)	11/15

Apparatus

The software and computer monitor apparatus was the same as in experiment 1.1, however, here an eye link II eye tracker (SR research Ltd, Ontario, Canada) was used. Participants' eye movements were recorded binocularly at 500HZ, with a spatial resolution of 0.01°. The parameters for pupil position and saccade onset were identical to those of experiment 1.1.

Visual stimuli

The display set had a grey background with a small grey fixation point (4 pixels x 4 pixels) in the centre. The face stimuli presented were the same faces used in experiment 1.1 (Langner et al., 2010), however these were converted to greyscale images using image manipulation software. The background, neck and shoulders were also replaced with a uniform grey background. There were 40 different face images in total, portraying 20 unique characters (ten of the characters were male, 10 female). All characters were gazing towards the left and to the right for the gaze cues. The faces were reduced in size, measuring approximately 9.7° in width by 15.5° in length. The size of the eyes remained consistent across the images, measuring 1.2 ° in width and 2.2 ° in length. In the arrows task, the cues consisted of two arrows pointing to both sides of the visual field (< >) for the non-directional cue, then to the left (<<) or the right (>>) for the directional cues. The arrows were grey in colour and measured 4.3 ° in width and 1.6 ° in height. All cues were presented centrally. The target was a white letter "A" which measured 1.4 ° wide and 1.6° high and was displayed 10.6° to the left or right of the fixation point.

Experimental tasks

The task was similar to experiment 1.1. The only differences were the stimulus onset asynchrony and stimuli presentation. For this study, there was no non-directional cue and the directional cue appeared for 200ms. See figure 2.6 for the order and time course of the stimuli presentation.

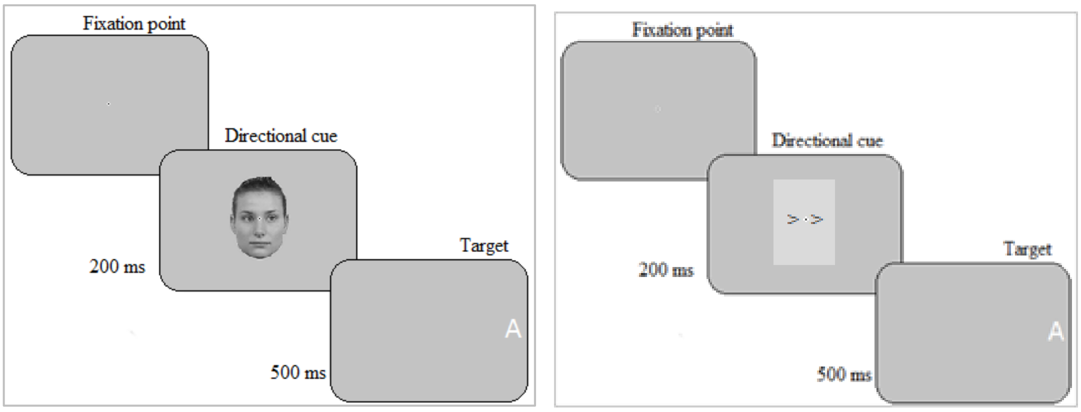

Figure 2.6. Order and time course of stimuli presentation, experiment 1.2

Procedure

The procedure and instructions for the lab-based task were the same as those used in experiment 1.1. However, because participant's eyes were being tracked binocularly, participants did not complete the Miles (1930) test of eye dominance before beginning the task.

2.2.3 Results

Eye movement data

Similarly to experiment 1.1, trials were removed if no response was recorded, if the response was anticipatory (< 80ms), or delayed (> 699ms) and if the amplitude of the saccade was less than 1°. Trials were also removed if the participant was improperly fixated. In this case, improper fixations were defined as a saccade beginning more than 1° from the central fixation point. This included the removal of 12.25% of all gaze trials (12.65% from the anti-saccade task and 11.85% from the pro-saccade task) and 13.15% of all arrow trials (11.15% from the anti-saccade task and 10.65% from the pro-saccade task). This led to the removal of a total of 11.5% of the trials. The dependent and independent variables for this experiment were identical to those of experiment 1.1. The data were inspected for any abnormalities and outliers, and where appropriate, transformations were applied. Initial screening again revealed skew in some experimental conditions that was not eliminated by transformations. Consistent with experiment 1.1, parametric analyses are reported for these cases to allow interaction effects to be investigated. However, precautionary nonparametric tests were also conducted. Results of the nonparametric analyses were mostly consistent with the findings from the parametric analyses, where these were not consistent this is reported.

Pro-saccade task SRT analysis

Table 2.7 shows the mean SRTs for gaze and arrow cues in the pro-saccade task for congruent cues, incongruent cues and each cue direction and target location condition. SRT data from the high AQ group showed signs of positive skew and non-normal distribution. Log and square root transformations did not improve the normality of the data so the original data were used for analysis.

For the pro-saccade task, the ANOVA showed no main effect of AQ group ($F(1,46) = 2.01$, $p = .163$), there was also no main effect of cue type ($F(1,46) = 1.48$, $p = .230$), cue direction ($F(1,46) = .206$, $p = .652$) or target location ($F(1,46) = .353$,

p = .555). There was a significant interaction between cue direction and target location (F(1,46) = 134.84, p < .001, η_p^2 =.75) and a significant interaction between cue direction and AQ group (F(1,46) = 4.39, p = .042, η_p^2 =.09). There was also a three way interaction between cue type, cue direction and target location (F(1,46) = 80.73, p < .001, η_p^2 =.64), and cue type, target location and AQ group (F(1,46) = 4.12, p = .048, η_p^2 =.08), and a four way interaction between AQ group, cue type, cue direction and target location (F(1,46) = 6.04, p = .018, η_p^2 =.12). No other interactions reached significance (all $F \leq 1.18$, $p \geq .284$, $\eta_p^2 \leq .03$).

To further investigate the four-way interaction, two separate three-way ANOVAs, one for each AQ group, were conducted. Cue type, cue direction and target location were the within-group factors.

Low scoring AQ group

The ANOVA for the low scoring AQ group showed no significant main effect of cue type (F(1,21) = 1.18, p = .290), cue direction (F(1,21) = 2.66, p = .118) or target location (F(1,21) = .243, p = .627). There was no significant interaction between cue type and cue direction (F(1,21) = .666, p = .424), or cue type and target location (F(1,21) = 2.98, p = .099). There was a significant two-way interaction between cue direction and target location (F(1,21) = 71.93, p < .001, η_p^2 =.77) and a significant three-way interaction between cue type, cue direction and target location (F(1,21) = 62.15, p < .001, η_p^2 =.75).

To further investigate this three-way interaction, two separate two-way ANOVAs were conducted for the arrow and gaze cues. For the low scoring AQ group an ANOVA on the arrow cues found no significant main effect of cue direction

Table 2.7.

Mean SRTs for pro-saccade task, experiment 1.2

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	168 (26.26)	166 (27.84)	169 (25.45)	155 (31.56)	192 (39.77)	156 (32.89)	184 (34.07)
High	158 (22.01)	155 (21.69)	161 (23.30)	148 (23.71)	170 (31.39)	149 (30.54)	173 (31.62)
	Arrow Cues						
Low	172 (32.83)	156(30.98)	188 (36.35)	167. (31.93)	169(27.70)	164 (28.42)	170 (26.45)
High	160 (26.29)	148 (25.53)	172 (29.36)	153. (23.71)	162 (25.60)	157 (22.59)	161 (25.05)

Table 2.8.

Mean error rates for pro-saccade task, experiment 1.2

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	.003(.006)	.001 (.005)	.004 (.011)	.002 (.008)	.004 (.013)	.000 (.000)	.005 (.025)
High	.003 (.010)	.000 (.000)	.008 (.021)	.000 (.000)	.003 (.012)	.000 (.000)	.012 (.035)
	Arrow Cues						
Low	.022 (.027)	.006 (.013)	.038 (.047)	.000 (.000)	.045 (.067)	.012 (.026)	.026 (.039)
High	.014 (.022)	.002 (.007)	.028 (.050)	.004 (.015)	.030 (.048)	.000 (.000)	.022 (.059)

(F(1,21) = 2.46, p = .132) or target location (F(1,21) = 3.42, p = .079). There was however a significant interaction between cue direction and target location (F(1,21) = 93.13, p < .001, η_p^2 =.82). Bonferroni corrected paired samples t-test with alpha set at p < .025 suggested significantly faster SRTs for congruent (right) cues (M = 156, SD = 32.89) than incongruent (left) arrow cues (M = 192, SD = 39.77) at the right target location (t(21) = 7.47, p < .001, d = 1.59) and significantly faster SRTs for congruent (left) cues (M = 155, SD = 31.56) than incongruent (right) arrow cues (M = 183, SD = 34.07) at the left target location (t(21) = 8.80, p < .001, d = 1.88) suggesting a significant congruency effect for arrow cues.

The ANOVA for the low AQ groups gaze cue SRTs found no significant main effect of cue direction (F(1,21) = .212, p = .650) or target location (F(1,21) = .274, p = .606). There was also no significant interaction between cue direction and target location (F(1,21) = 2.52, p = .128) suggesting a lack of a congruency effect for gaze cues from those with a low AQ score.

High scoring AQ group

The three-way ANOVA for the high AQ group's SRT data also revealed no significant main effect of cue type (F(1,25) = .334, p = .569), cue direction (F(1,25) = 1.65, p = .212) or target location (F(1,25) = .133, p = .719). Similarly to the low AQ group, there was a significant interaction between cue direction and target location (F(1,25) = 62.25, p < .001, η_p^2 =.71) and a significant three-way interaction between cue type, cue direction and target location (F(1,25) = 22.71, p <.001, η_p^2 =.48).

To follow up this three-way interaction, a separate two-way ANOVA on arrow cued SRTs only, suggested no significant main effect of cue direction (*F*(1,25) = .922, *p* = .346) or target location (*F*(1,25) = .023, *p* = .882). There was a significant interaction between cue direction and target location (*F*(1,25) = 55.81, *p* <.001, η_p^2 =.69). Bonferroni corrected paired samples t-tests with alpha set at *p* < .025 suggested significantly faster SRTs for congruent (right) cues (M = 149, SD = 30.54) than incongruent (left) arrow cues (M = 170, SD = 31.39) at the right target location (*t*(25) = 7.27, *p* < .001, *d* = 1.43) and significantly faster SRTs for congruent (left) cues (M = 148, SD = 23.71) than incongruent (right) arrow cues (M = 173, SD = 31.61) at left target locations (*t*(25) = 5.83, *p* < .001, *d* = 1.14), again reflecting a significant congruency effect.

A separate two-way ANOVA on gaze cued SRTs suggested no significant main effect of cue direction (*F*(1,25) = .373, *p* = .547) or target location (*F*(1,25) = .918, *p* = .347) for the high AQ group. There was a significant interaction between cue direction and target location (*F*(1,25) = 12.02, *p* = .002, η_p^2 =.04). Bonferroni corrected paired samples t-test with alpha set at *p* < .025 suggested significantly faster SRTs for congruent (left) cues (M = 153, SD = 23.71) than incongruent (right) gaze cues (M = 161, SD = 25.05) for the left target location (*t*(25) = 3.96, *p* = .001, *d* = 0.78). The difference between SRTs for congruent (right) cues (M = 157, SD = 22.59) and incongruent (left) gaze cues (M = 162, SD = 25.60) for right target locations was not significant (*t*(25) = 1.68, *p* = .106). This suggests a significant gaze congruency effect only for targets appearing on the left.

Pro-saccade task error rate analysis

Similarly to the error rates for the pro-saccade task in experiment 1.1, the variables 'cue direction' and 'target location' were collapsed into a single 'congruency' (congruent/incongruent) variable. One participant from each group was identified as an outlier for their gaze cue errors. Their scores were replaced with the mean plus two times the standard deviation. See table 2.8 for the means and standard deviations for error rates in the congruent and incongruent gaze and arrow conditions.

All error rate data were positively skewed. Furthermore, for congruent cues, the variances were significantly different between the two groups (arrow cues, $F(1,46) = 7.08$, $p = .011$; gaze cues, $F(1,46) = 5.23$, $p = .027$). Transformations of the data did not improve this; this was due to ceiling level performance from all participants in the high AQ group for congruent gaze cues. The original data were therefore used for analysis.

A 2 (group, high AQ/low AQ) × 2 (cue type, arrows/gaze) × 2 (congruency, congruent/incongruent) ANOVA was conducted. This revealed no significant main effect of group ($F(1,46) = .274$, $p = .603$). There was a significant main effect of cue type ($F(1,46) = 21.58$, $p < .001$, $\eta_p^2 = .32$) and congruency ($F(1,46) = 17.91$, $p < .001$, $\eta_p^2 = .28$). There was also a significant interaction between cue type and congruency ($F(1,46) = 17.95$, $p < .001$, $\eta_p^2 = .28$). To further investigate this interaction, Bonferroni corrected paired samples t-tests with alpha set at $p < .0125$ were conducted to compare error rates for congruent gaze and arrow cues and incongruent gaze and arrow cues. This showed significantly lower error rates for congruent than incongruent arrow cues ($t(47) = -4.45$, $p < .001$ $d = 0.64$). The difference between congruent and incongruent gaze cues was not significant ($t(47) = -2.39$, $p = .021$) . Furthermore, error rates for congruent arrow cues (M= .001, SD = .003) were not significantly different than error rates for congruent gaze cues ($t(47) = 2.19$, $p = .034$). Incongruent arrow cues (M = .033, SD = .048) however, elicited significantly higher error rates than incongruent gaze cues (M = .006, SD = .017) ($t(47) = 4.51$, $p <. 001$, $d= 0.65$). This interaction is shown in figure 2.7.

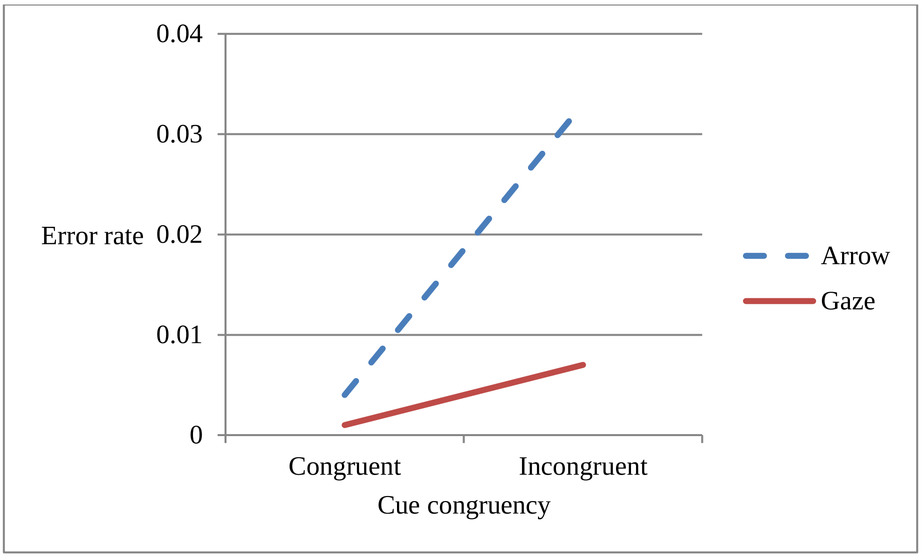

Figure 2.7. Error rates for congruent and incongruent gaze and arrow cues, pro-saccade task, experiment 1.2.

Overall, results of the pro-saccade task suggest that congruency had a significant effect on both groups SRTs for arrow cues. A congruency effect for gaze cues however was only apparent in the high AQ group, and only for targets appearing on the left. No gaze congruency effect was found for those in the low AQ group. Error rates for both groups for gaze and arrow cues were low, however, incongruent arrow cues elicited significantly more errors than congruent arrow cues and both congruent and incongruent gaze cues.

Anti-saccade task saccadic reaction time analysis

Five outliers from the high AQ group and four outliers from the low AQ group were removed from the analysis for the anti-saccade task as they performed at chance level (> 50% errors). The remaining participants' data from the high AQ group were non-normal and showed signs of positive skew in two conditions. The data were subsequently transformed using log and square root transformations. Neither of these transformations improved the normality of the data or eliminated the skew so the original data were used for analysis. Table 2.9 shows the mean SRTs for the anti-saccade task.

The ANOVA showed no main effect of AQ group, ($F(1,37) = 1.61$, $p = 2.12$), cue type ($F(1,37) = .079$, $p = .780$), cue direction ($F(1,37) = .004$, $p = .953$) or target location ($F(1,37) = .137$, $p = .713$). Again, there was a significant interaction between cue direction and target location ($F(1,37) = 72.16$, $p < .001$, $\eta_p^2 =.66$) suggesting a congruency effect. There was also a significant three-way interaction between cue type, cue direction and target location ($F(1,37) = 11.70$, $p = .002$, $\eta_p^2 = .24$). No other interactions reached significance (all $F \leq 1.62$, $p \geq .211$, $\eta_p^2 \leq .04$).

To further investigate this three-way interaction, two 2 (cue direction, left/right) × 2 (target location, left/right) ANOVAs were conducted on the data from the gaze and arrow cue conditions separately.

Arrow cues

The ANOVA for arrow cue SRTs revealed no significant main effect of cue direction ($F(1,38) = .384$, $p = .539$), or target location ($F(1,38) = .220$, $p = .642$). There was a significant interaction between cue direction and target location $F(1,38)$

= 56.54, $p < .001$, $\eta_p^2 = .60$). To further investigate the interaction between cue direction and target location, Bonferroni corrected paired samples t-tests with alpha set at $p < .025$ were conducted to compare each cue direction and target location. This confirmed the significant congruency effect with significantly faster responses for congruent (left) cues (M = 229, SD = 37.34) than incongruent (right) cues (M = 251, SD = 33.36) for targets appearing on the left ($t(38) = -7.60$, $p < .001$, $d = 1.22$) and significantly faster responses for congruent (right) cues (M = 229, SD = 30.86) than incongruent (left) cues (M = 254, SD = 35.85) for targets appearing on the right ($t(38) = 5.23$, $p < .001$, $d = 0.84$).

Gaze cues

The ANOVA for gaze cue SRTs revealed no significant main effect of cue direction $F(1,38) = .534$, $p = .469$), or target location $F(1,38) = .059$, $p = .810$). There was a significant interaction between cue direction and target location $F(1,38) = 21.16$, $p < .001$, $\eta_p^2 = .36$). To further investigate the interaction between cue direction and target location, Bonferroni corrected paired samples t-tests were conducted with alpha set at $p < .025$ to compare each cue direction and target location. This confirmed the significant congruency effect with significantly faster responses for congruent (left) cues (M = 237, SD = 33.67) than incongruent (right) cues (M = 247, SD = 31.82) for targets appearing on the left ($t(38) = -2.99$, $p = .005$, $d = 0.49$) and significantly faster responses for congruent (right) cues (M = 235, SD = 30.83) than incongruent (left) cues (M = 247, SD = 33.55) for targets appearing on the right ($t(38) = 4.18$, $p < .001$, $d = 0.67$).

Anti-saccade error rate analysis

The anti-saccade error rate data showed evidence of skew and non-normal distribution. The data were therefore transformed using a square root transformation and log transformation. Neither transformation improved the normalcy of the data so the original data were used for analysis. Table 2.10 shows the mean error rates.

A 2 (group, high/low) × 2 (cue type, gaze/arrows) × 2 (congruency, congruent/incongruent) ANOVA was conducted for the error rate data. This revealed no significant effect of group (F(1,37) = 0.35, p = .558). The effect of cue type approached but did not reach significance (F(1,37) = 3.97, p = .054, η_p^2 =.10). It must be noted that non-parametric Wilcoxon rank sign tests suggested that this main effect of cue type was significant (p = .031) with more errors for arrow than gaze cues (all other results were consistent between parametric and nonparametric analyses). The ANOVA also suggested that there was a significant main effect of congruency (F(1,37) = 20.92, p < .001, η_p^2 = .36) and a significant interaction between cue type and congruency (F(1,37) = 14.29, p = .001, η_p^2 =.28). This interaction can be seen in the graph in figure 2.8.

Bonferroni corrected paired samples t-tests with alpha set at p < .0125, suggested a significant congruency effect for arrow cues with significantly fewer errors for congruent arrows (M = 0.13, SD = 0.12) than incongruent arrow cues (M = 0.28, SD = 0.18) (t(38) = -4.80, p < .001, d = 0.77). This congruency effect was not significant for gaze cues (t(38) = -1.98, p = .056) (congruent gaze cue errors M = 0.16, SD = 0.10, and incongruent gaze cue errors, M = 0.19, SD = 0.12). No significant differences in error rates were found between congruent gaze and arrow

Table 2.9.

Mean SRTs for anti-saccade task, experiment 1.2

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	248 (27.54)	242 (26.10)	254 (29.19)	242 (31.88)	254 (32.23)	243 (23.73)	253 (33.46)
High	235 (31.31)	230 (33.63)	241 (30.90)	233 (35.37)	241 (34.20)	228 (34.99)	241 (30.18)
	Arrow Cues						
Low	244 (34.06)	233 (33.87)	258 (35.71)	234. (43.34)	261 (34.52)	233 (30.65)	259 (40.97)
High	233 (29.50)	224 (29.36)	247 (29.71)	224 (31.69)	243 (30.87)	225 (31.29)	250 (31.27)

Table 2.10.

Mean error rates for anti-saccade task, experiment 1.2

	Overall	Congruent cues	Incongruent cues	Cue left, target direction left	Cue left, target direction right	Cue right, target direction right	Cue right, target direction left
AQ group	Gaze cues						
Low	0.17 (0.09)	0.16 (0.10)	0.18 (0.10)	0.15 (0.13)	0.16 (0.13)	0.16 (0.11)	0.20 (0.13)
High	0.18 (0.11)	0.16 (0.10)	0.20 (0.14)	0.19 (0.15)	0.19 (0.14)	0.14 (0.11)	0.21 (0.16)
	Arrow Cues						
Low	0.19 (0.11)	0.13 (0.13)	0.25 (0.16)	0.14 (0.13)	0.24 (0.23)	0.13 (0.15)	0.27 (0.15)
High	0.21 (0.12)	0.13 (0.11)	0.30 (0.19)	0.14 (0.16)	0.32 (0.20)	0.13 (0.10)	0.29 (0.20)

cues (t(38) = -1.60, p = .188), but significantly more errors were made for incongruent arrow cues than incongruent gaze cues (t(38) = 3.66, p =.001, d =0.59).

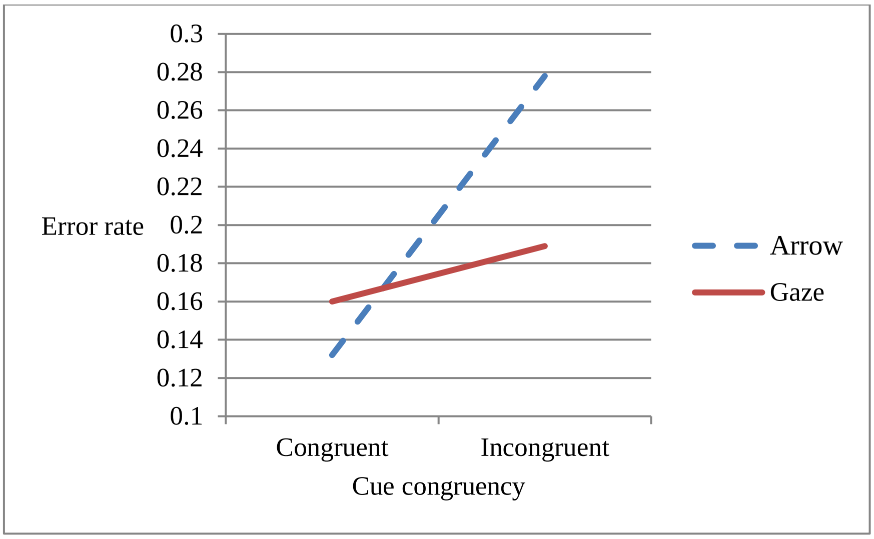

Figure 2.8. Error rates for congruent and incongruent gaze and arrow cues, anti-saccade task, experiment 1.2

Bonferroni corrected paired samples t-tests with alpha set at $p < .0125$, suggested a significant congruency effect for arrow cues with significantly fewer errors for congruent arrows (M = 0.13, SD = 0.12) than incongruent arrow cues (M = 0.28, SD = 0.18) (t(38) = -4.80, $p < .001$, d = 0.77). This congruency effect was not significant for gaze cues (t(38) = -1.98, p = .056) (congruent gaze cue errors M = 0.16, SD = 0.10, and incongruent gaze cue errors, M = 0.19, SD = 0.12). No significant differences in error rates were found between congruent gaze and arrow cues (t(38) = -1.60, p = .188), but significantly more errors were made for incongruent arrow cues than incongruent gaze cues (t(38) = 3.66, p =.001, d =0.59).

Overall, the results of the anti-saccade analysis suggest that SRTs for both high and low AQ groups showed similar congruency effects for arrow and gaze cues with faster responses for congruent cues. The error rate analysis suggested a significant congruency effect for errors in the arrow cue condition but not in the gaze cue condition. Overall, more errors were made for incongruent arrow cues.

2.2.4 Discussion

The aim of experiment 1.2 was to strictly control for maintenance of central fixation until target onset. The stimulus, its presentation and SOA were therefore different for this study. To reduce instances of improper fixation, the gaze stimulus was reduced in size and the non-directional stimuli was removed. The cues were also converted to grey-scale to make them more visually similar. Finally, the SOA in this study was reduced from 400ms to 200ms. This SOA was taken from the cueing task by Koval et al. (2005), which measured the effect of non-predictive gaze cues on pro and anti-saccades. These changes made the stimuli presentation and style of the gaze cues similar to that of Koval et al. (2005). These steps were taken to both improve control of central fixation and with the aim to increase the sensitivity for detecting group differences. Researchers have previously suggested that shorter cueing SOAs may elicit greater differences in attentional cueing between ASD and TD participant groups (Landry & Burack, 2009; Landry & Parker, 2013). So in an attempt to elucidate behavioural differences between individuals with high and low autistic traits, the SOA was reduced for this study.

As with experiment 1.1, the arrow cue was introduced to the paradigm to compare SRTs and error rates between social and non-social cues. This was an attempt to again replicate the findings of Koval et al. (2005), testing their robustness, and expand on their findings by comparing social and non-social orienting at a shorter SOA.

Although changes in stimuli presentation between experiment 1.1 and 1.2 means that direct comparisons should me made with caution, some interesting differences were found. Contrary to the results of experiment 1.1, the current study did not reveal any differences in the overall speed of saccadic responses to gaze and arrow cues. Experiment 1.1 suggested that SRTs for arrow cues were faster overall than SRTs for gaze cues. Here, both cues elicited equivalent SRTs. This may have been due to the shorter cue presentation time, which gave participants less time to respond. This result is however consistent with some previous findings in both overt and covert cueing paradigms where gaze and arrow cues have generated similar reaction times (Kuhn et al., 2007; Kuhn et al., 2010; Pruett et al.,2011; Ristic et al., 2002; Tipples, 2002).

Consistent with experiment 1.1, this study found no main effects of autistic traits. However, separate analysis of SRTs for the high and low AQ groups revealed differences in congruency for the pro-saccade task. While both groups showed a congruency effect for arrow cues, only the high AQ group showed a congruency effect for gaze cues, and only when the targets were presented on the left. This is opposite to the laterality effect found in typically developing controls by Vlamings et al. (2005) where a significant congruency effect for rightward gaze cues and not leftward gaze cues was found. Instead, the laterality effect found for gaze cues in the high AQ group in the current study is consistent with the pattern of responses from children with ASD (Stauder, Bosch & Nuij, 2011) and parents of children with ASD

(Scheeren & Stauder, 2008) reported in follow-up studies of Vlamings et al.'s (2005) study. These studies found a congruency effect for leftward but not rightward gaze cues. It must be noted that these previous studies found these laterality effects with an SOA of 400ms where the current study (1.2) used an SOA of 200ms. Also, there was no difference in AQ scores between mothers and fathers with and without children with ASD in Scheeren and Stauder's (2008) study. This could suggest that AQ scores may not be associated with gaze cueing, but that gaze cueing atypicalities may be specific to the BAP and individuals with ASD. This interpretation implies that individuals on the BAP and TD controls may not use the same mechanisms for cueing tasks, thus eliminating any differences attributable to autistic traits that would be found in the TD population (e.g. criticism leveled at the AQ by Gregory & Plaisted Grant, 2013). Alternatively, the AQ may not have been sensitive enough to detect differences in autistic traits between the parents who participated in this cueing task. This interpretation would suggest a distinct lack of sensitivity in the AQ, however, previous studies have found differences in cueing task performance between those with high and low AQ scores by using the AQ questionnaire in the same way as it was used in the current study (e.g. Bayliss & Tipper, 2005; Zhao, Uono, Yoshimura & Toichi, 2015). Furthermore, in experiment 1.2, differences in congruency effects for gaze cues were detected between the high and low AQ groups for the pro-saccade task.

The lack of a congruency effect for pro-saccade gaze cues in the low AQ group in the current study suggests that when a saccadic response towards the target was required, eye movements of participants low in autistic traits were not influenced by gaze cues but were influenced by arrow cues. This is contrary to our expectations. In light of the reduced saliency for social cues found in ASD, it was anticipated that participants with higher autistic traits would be less influenced by gaze cues, rather than the other way around. The lack of congruency effect for the low AQ group in the gaze cue condition suggests that they were better able to completely ignore the cue here. Alternatively, the removal of the non-directional gaze cue depicting a face gazing directly at the participant may have reduced the social relevance of this cue for the low AQ group.

For the anti-saccade task, no group differences in SRTs were found. Both groups demonstrated significant validity effects for both gaze and arrow cues. Correct saccades away from the target were facilitated by congruent cues. This echoes the results from experiment 1.1 and supports the findings of Koval et al. (2005), Wolohan and Crawford (2012) and Gregory and Hodgeson (2012). Overall, the SRT findings from this study are further evidence that a pro-saccade task instruction causes preparation of a saccade in the direction of the cue and an anti-saccade instruction causes preparation of a saccade in the opposite direction of the cue.

Analysis of the error rates in experiment 1.2 demonstrated significant interactions between cue type and congruency. In both the pro and anti-saccade tasks more errors were found for incongruent arrow cues than congruent arrow cues, suggesting a significant effect of congruency for arrow cues. This congruency effect was not found for gaze cue errors. This suggests that participants were more likely to erroneously saccade to follow an arrow cue in the pro-saccade task and more likely to saccade away from the direction of the arrow cue in the anti-saccade task. It must be noted here that error rates for gaze cues in the pro-saccade task were very low and at ceiling level for the high AQ group for the congruent condition thus limiting the conclusions that can be drawn from this task. The error rate result from this anti-saccade task is at odds with the findings from the anti-saccade task in experiment 1.1 where significantly more errors were reported for incongruent gaze cues than arrow cues. The result from experiment 1.2 cannot be explained by any speed/accuracy trade off because SRTs to both gaze and arrow cues were equivalent. This therefore suggests that when the cue is presented for only a brief time, arrow cues may be responded to more automatically than gaze cues.

Overall, the results of studies 1.1 and 1.2 did not fully support the hypotheses. In both studies, no differences in overall error rates or the overall speed of visual orienting to gaze and arrow cues were found between those with high and low levels of autistic traits. Subtle differences in congruency effects were found between the groups for gaze cues in experiment 1.2. Here, the low AQ group did not demonstrate a congruency effect for gaze cues. The high AQ group on the other hand demonstrated a lateralised congruency effect similar to that previously found in children with ASD and their parents (Schereen & Stauder, 2011; Stauder, Bosch & Nuij, 2011). However, this finding was not consistent across studies 1.1 and 1.2, or across pro and anti-saccade tasks. Furthermore, this effect was detected at a short stimuli presentation and SOA of 200ms, not the longer SOA of 400ms as used by Vlamings et al., (2005), Schereen and Stauder (2008) and Stauder, Bosch and Nuij (2011). This suggests that higher autistic traits may be associated with atypicalities in the lateralization of gaze cueing but this effect could be shorter lived than for those with ASD or the BAP and only apparent in a pro-saccade task with rapidly presented stimuli. Laterality effects are generally not explored in cueing studies of both TD and ASD populations. These findings suggest that this may warrant further research.

In terms of cue type, the two studies again differed in their findings. In experiment 1.1 gaze cues elicited longer SRTs for both pro and anti-saccade tasks and increased errors in the anti-saccade task suggested more reflexive gaze cueing than arrow cueing. Conversely, no differences in SRT between the cues were found in experiment 1.2 but increased errors for incongruent arrow cues suggested more reflexive orienting for arrow cues than gaze cues. The difference in cue presentation and SOA between these studies prevents direct comparison. Experiment 1.1 used a non-directional cue before the presentation of the directional cue for 400ms, whereas experiment 1.2 presented directional cues only and for 200ms. The lack of consistency between the results highlights the diverse findings that can be elicited by variations in SOA and cue presentation. It is likely that the differences in methodology across cueing studies contribute to the equivocal picture of visual orienting to gaze and arrow cues in ASD and TD populations. Future studies should focus on more systematically varying these elements of the cueing task and further investigating how cue direction and target location affect cueing as well as overall congruency effects.

In conclusion, these studies suggest that gaze cueing may differ very subtly in typically developing individuals with high and low levels of autistic traits. However, these differences do not appear to be robust and may only occur under specific cueing circumstances. Future research should continue to more systematically investigate exactly when and to what extent gaze cueing in the TD population varies in association with increased levels of autistic traits. The most interesting finding of the current studies was that participants' saccadic responses were adapted to be in line with the tasks goals (pro or anti-saccade). This supports the idea that attention to gaze cues is not completely reflexive and can also be voluntarily controlled. This also highlights the flexible nature of attention to central cues that can be modified according to contextual demands of the task goals and stimuli. Indeed, efforts to uncover what contributes to problems in social and joint attention in ASD will likely be enhanced by increasing the contextual demands of the stimuli and the task. This could include the social and emotional complexity of cues and targets. Increasing the social demands of the task could provide more robust effects that may prove more informative about social orienting and joint attention in ASD and along the broader autism continuum.

Chapter 3: Study 2

Responding to and initiating joint attention with a virtual character in children with and without ASD

3.1 Introduction

The vast body of research using structured Posner style gaze cueing paradigms has confirmed that children and adults with autism can detect and follow gaze when prompted and that observing a gaze shift modulates their spatial attention. The evidence that individuals with ASD may distinguish less between gaze and non-social cues than their TD peers suggests that this skill may be achieved via non-social mechanisms (e.g. Vlamings et al., 2005). Nevertheless, reflexive gaze cueing seems to be intact in ASD and the basic ability to follow gaze is not impaired (e.g. Kuhn et al., 2010; Senju et al., 2004).

Although useful in investigating how gaze modulates reflexive spatial attention, these paradigms have their limitations regarding what they can reveal about triadic joint attention. When considering the triadic definition of joint attention, this includes at least three components: 1) An 'initiator' of joint attention who directs another's attention; 2) A 'responder' who responds to the initiator's bid for joint attention; and 3) the 'referent object' to which both individuals focus their attention. Experimental paradigms exploring joint attention have mainly focused on investigating how the 'responder' detects or looks at a target preceded by a gaze cue. Here, the target object is often an arbitrary symbol such as a dot, letter or number and the task requires minimal subsequent processing of the target, typically location detection or immediate discrimination. This is not greatly informative about how deeply the referent is being attended to and processed in a triadic joint attention situation. Furthermore, evidence from cueing studies suggests that the effect of gaze is not limited to spatial attention shifts but gaze shifts can also affect object evaluations, memory and categorisation (Bayliss et al., 2007; Bayliss et al., 2013; Becchio et al., 2008; Dodd et al., 2012). A more complicated task requiring the target of joint attention to be processed more elaborately may allow for greater understanding of how information about the referent object is processed and retained during joint attention. Furthermore, the narrow focus solely on the reactions of the 'responder' means much less is known about the 'initiator' of the joint attention interaction. Recent studies have suggested potential facilitative effects for referent object processing in situations where typically developing individuals both respond to and initiate joint attention. The cognitive effects of joint attention in ASD are less well understood. Further investigation of the more overlooked components of joint attention is necessary for a fuller understanding of joint attention in both typical and atypical development.

Advances in methodology mean that effects of responding to joint attention (RJA) and initiating joint attention (IJA) on information processing are beginning to be investigated experimentally. In a recently developed virtual reality joint attention task (Kim & Mundy, 2012), participants are asked to follow (RJA condition) and guide (IJA condition) a virtual avatar's gaze shift to a series of referent images to be memorised for a subsequent memory test. Studies using this paradigm have reported that typically developing adults (Kim & Mundy, 2012; Kim, Jang & Kim, 2015), typically developing children and children with symptoms of ADHD (Mundy et al., 2016) show significantly better memory for referent images in the IJA condition than the RJA condition. Interestingly, this effect was not found for children with ASD who did not benefit from enhanced information processing in the IJA condition (Mundy et al., 2016).

This evidence suggests that object representations and encoding, which appear to be modulated by joint attention in typical development, may be reduced in ASD. If this is the case, it may be helpful to investigate the extent to which referent objects in JA are processed in ASD and how this differs in RJA and IJA. This is particularly pertinent in considering models of joint attention, such as social cognition models (Baron-Cohen, 1995; Tomasello, 1995) and the parallel-distributed processing model (Mundy, Sullivan & Mastergeorge, 2009), where JA is positioned as a social information processing and learning system. Further investigation of the more overlooked components of joint attention is necessary for a clearer and fuller understanding of joint attention in both typical and atypical development.

A complete picture of joint attention requires knowledge of all three of the components of joint attention- the responder, initiator and the referent object. With this in mind, the studies in the following two chapters of this thesis will adapt the virtual reality paradigm developed by Kim and Mundy (2012). These studies will use a gaze contingent computer avatar to investigate how children with autism, typically developing children and typically developing adults with different levels of autistic traits respond to and initiate joint attention to a referent image. These studies will examine how RJA and IJA affect processing of the referent image. Participants' recognition memory for the referent images will be measured to gain an insight into their depth of processing. This study will therefore incorporate the three main components of JA.

For these studies, the emulation of joint attention with the avatar is in line with the structure proposed by Carptenter & Liebal (2011) for 'top down' joint attention and the gaze sequence proposed by van der Weiden et al. (2010). This includes a three-step initiation, reference and sharing look. The interaction with the avatar begins with the initiation look. This involves the avatar facing towards the participant in mutual gaze. This aims to establish ostensive communication between the participant and the character, for which mutual gaze is vital (Marno et al., 2014; Senju & Johnson, 2009). This is followed by a 'reference look' to one of two empty placeholders. In RJA trials, the avatar will initiate the reference look. In IJA trials the participant will initiate the reference look. To both initiate and respond to the reference look the avatar will execute a head turn and concurrently shift his gaze towards the relevant placeholder. A head turn was included here over a gaze shift only to enhance the salience of this joint attention action and give participants the best chance to view how the avatar has responded to their gaze shifts (without including additional non-JA auditory or visual cues). When both the participant and avatar are fixated on the placeholder the referent image will then appear for the 'show target period' where participants will be tasked with remembering the image presented for a later recognition test. Target images in RJA trials are the images that appear in the placeholder the avatar looks at, and target images in IJA trials are the images that appear in the placeholder the participant chooses to look at and guide the avatar's attention towards. The decision to make the target images appear when both the participant and avatar are fixated on the empty placeholder was an attempt to control for target viewing times as much as possible. This was also an attempt to make the RJA and IJA trials as similar in presentation as possible with the only difference being whether the participant or the avatar initiated the gaze shift to the relevant placeholder. This allows the opportunity for attentional allocation to the avatar's reference look in the RJA condition, and to the avatar's response to participant's reference look in the IJA condition, to be the same. When the referent image has been shown and subsequently disappears the character's gaze will linger on the empty placeholder. This was to make it as clear as possible to participants that both themselves and the avatar were looking at the image at the same time. To finish the trial, the avatar will then look back to the participant for a 'sharing look'. The addition of a sharing look is unique to this experiment and was not included in the Kim and Mundy (2012) or Mundy et al., (2016) procedure. The bidirectional 'initiation' and 'sharing' looks were included with the aim to increase the joint attention valence of the avatar and turn mutually seen images into as sophisticated a JA interaction as possible within the boundaries of the computer screen. It must be noted that due to the computer based nature of the task and because the interaction is with an animated character, the current study cannot claim to be an investigation of naturalistic joint attention interactions where both parties can 'know together' (Carpenter & Liebal, 2011) that they are engaging in joint attention. It does however close the "joint attention triangle" (Carpenter & Liebal, 2011) and engages participants as both responders *and* initiators in simulated joint attention with the avatar. This allows us to investigate how intentional following and guiding of a social character's gaze affects the processing of the referent image.

JA tasks and hypotheses

Participants in the following studies will complete two separate joint attention tasks (experiment 2.1 and experiment 2.2) with the avatar where their recognition memory for the target images will be measured. In joint attention experiment 2.1 participants will follow the avatar's gaze to his chosen placeholder (RJA condition) and initiate a gaze shift towards their chosen placeholder (IJA condition) to view the target images. This will allow a comparison of effects of RJA and IJA on recognition memory for target images.

In joint attention experiment 2.2 all trials will be similar to those in the IJA condition in experiment 2.1. Here participants will always choose which placeholder to view and subsequently which target image to remember. Their gaze shifts will either elicit a congruent gaze shift from the avatar where he will follow their gaze to the appropriate placeholder (gaze-followed condition) or an incongruent gaze shift where the avatar will look at the opposite placeholder (gaze-ignored condition). This task aims to compare the effects on encoding of the target images in IJA when the participant's gaze shift is reciprocated vs. ignored.

Throughout the course of experiments 2.1 and 2.2, allocation of attention to the target image, the opposite non-target image and the avatar will be measured during the critical period when the target image is shown. This is in an effort to compare how participants allocate their attention when tasked to remember the referent whilst responding to and initiating joint attention.

Study 2 hypotheses

In the following study, a group of school aged children with ASD and a group of age and IQ matched TD controls will complete both JA experiments 2.1 and 2.2. Consistent with previous findings, TD children are expected to show enhanced recognition memory for target images in trials emulating IJA compared to trials emulating RJA. Due to reduced referential significance and saliency of gaze and overall weaker engagement in joint attention in ASD, this difference between the RJA and IJA condition is not expected in the group with ASD. In experiment 2.1 it is expected that the TD children will demonstrate significantly better recognition memory for target images in the IJA condition than the RJA condition. This effect is not expected in the ASD group or is expected to be considerably weaker. In experiment 2.2 it is expected that TD children will show greater recognition memory for the target images when the avatar follows their gaze shift, rather than ignores it. This effect again is not expected in the ASD group where memory for the target image is expected to be the same between the gaze followed and gaze ignored conditions.

3.2 Image stimuli validation

The images used for joint attention experiments 2.1 and 2.2 were images of faces, houses and abstract patterns. These were from Kim and Mundy's (2012) joint attention study and supplemented with additional face, abstract and house images. To validate these images for use in this study, two online memory tasks (memory task 1 & 2) were conducted. Memory task 1 used the stimuli intended for joint attention experiment 2.1 and memory task 2 used the stimuli intended for joint attention experiment 2.2. The images were randomly assigned to one of the two tasks. These were designed to test the suitability of the images for both joint attention tasks.

3.2.1 Method

Participants

Sixty-two participants consented to take part in memory task 1 (12 males, M = 33.25 years old, SD = 11.55, and 50 females, M= 30.39 years old, SD = 11.05) and sixty-one participants took part in memory task 2 (13 males, M = 32.46 years old, SD = 8.28, and 48 females, M = 33.37 years old, SD = 11.70). Participants were recruited via online community fora and mailing lists for the University of Strathclyde student population.

Materials

Two hundred and eighty eight images were used in the following studies. These images comprised 96 faces, 96 houses and 96 abstract images. The face images were taken from normalised versions of the CAL/PAL faces database (Minear & Park, 2004) created by Ebner (2008) and the Karolinska directed emotional facial expressions (KDEF) database (Lundqvust, Flykt, & Ohman, 1998). The faces comprised 96 unique characters, 48 males and 48 females, portraying a neutral facial expression, shown on a grey background.

The house images comprised a total of 96 colour house images, 44 of which were taken from the house images used as stimuli by Kim and Mundy (2012), with the remaining 54 colour house images sourced from the internet. The houses were chosen to be similar but distinct from the original images of Kim and Mundy (2012). Thirty of the abstract images were also taken from the original Kim and Mundy (2012) stimuli set. A further 66 coloured images of abstract designs were sourced from the Internet and were chosen on the basis of their abstract nature.

Images from the house and abstract categories were randomly split into two, one half for each of the memory tasks, 1 and 2. An equal number of the original stimuli from Kim & Mundy (2012) were included in both studies. The CAL/PAL face images were assigned to memory task 1 and the KDEF face images were used for memory task 2. The stimuli from each image category were then further randomly split into three groups to allow for three different versions of memory task 1 and 2. This led to two separate image sets (1 & 2) with three different variations of the task (1, 2 & 3), each with 48 unique target images (16 faces, 16 houses 16 abstract images), and 96 unique non-target images (32 faces, 32 houses, 32 abstract images). To ensure each image was seen as a target in one of the three versions of task 1 and 2, the images used as targets were fully counterbalanced.

The memory tasks were created and run on Qualtrics online survey software and insight platform (Qualtrics, 2014). Each task consisted of four blocks of 12 target images (4 face, 4 house and 4 abstract images). Target images were randomly assigned to each block and their presentation was subsequently randomised. A test block, consisting of 36 images followed each block. These included 12 target images, and 24 non-target images (each comprising 8 face, 8 house and 8 abstract images), all randomly presented.

Procedure

Participants were randomly assigned to one of three versions of the memory tasks. They were instructed that they would be presented with a series of face, house and abstract images that they should study carefully as their recognition would be tested later. For each block, 12 images (4 faces 4 house & 4 abstract images) were presented sequentially on the centre of the screen for 1000ms. Participants were then instructed that after a 30 second pause they would be presented with a series of images and asked to indicate if they recognised the image. When the 30 seconds had elapsed the test phase began. Twelve target and 24 non-target images were sequentially presented and participants were asked if they recognised the image from before. They clicked “yes” or “no” to indicate their response. Participants completed 4 blocks in total, taking approximately 20 minutes to complete.

3.2.2 Results

The number of images each participant correctly remembered was used to obtain their percentage accuracy. The hit rate and false alarm rate for each image category was also calculated. As some participants scored the maximum number of hits and no false alarms for some categories, hit rates and false alarms were calculated using a loglinear approach (Hautus, 1995). This involves adding 0.5 to each participant’s actual total number of hits and false alarms and adding 1 to the total number of possible hits and possible false alarms, before the hit and false alarm rates are calculated. To obtain hit rates, participants’ total number of hits (+ 0.5) was divided by the total number of target images (+ 1). False alarm rates were calculated by dividing participants total number of false alarms (+ 0.5) by the total number of foils (+ 1). This approach has been recommended regardless of the occurrence of extreme scores (Stanislaw & Todorov, 1999). The z-scores of the false alarm rates were then subtracted from the z-scores of the hit rates to find the *d’* value, as described by Stanislaw & Todorov (1999). Table 3.1 shows the overall means and standard deviations for percentage accuracy and *d’* for each version of memory task 1. and 2.

Table 3.1.

Mean and Standard Deviation percentage accuracy and d' for images remembered, memory tasks 1 & 2

Image category	Task version	Percentage accuracy	*d'*
House	1-1	84.82 (16.12)	2.70 (0.78)
	1-2	82.23 (15.35)	2.66 (0.82)
	1-3	84.94 (13.45)	2.98 (0.51)
	Total	84.07 (14.78)	2.79 (0.71)
Face	1-1	88.69 (10.19)	2.90 (0.65)
	1-2	87.82 (13.57)	2.81 (0.78)
	1-3	91.19 (12.57)	3.12 (0.76)
	Total	89.31 (12.57)	2.95 (0.73)
Abstract	1-1	77.38 (20.20)	2.65 (0.86)
	1-2	83.55 (13.69)	2.82 (0.68)
	1-3	86.08 (13.21)	2.86 (0.62)
	Total	82.36 (16.22)	2.78 (0.72)
House	2-1	86.90 (14.37)	3.05 (0.71)
	2-2	86.45 (17.45)	2.97 (0.84)
	2-3	87.17 (14.35)	2.76 (0.82)
	Total	86.85 (15.11)	2.93 (0.78)
Face	2-1	92.56 (9.61)	2.73 (0.81)
	2-2	90.27 (9.87)	2.81 (0.96)
	2-3	91.12 (8.67)	2.92 (0.63)
	Total	91.38 (9.28)	2.82 (0.78)
Abstract	2-1	84.82 (14.99)	3.04 (0.72)
	2-2	83.33 (18.44)	2.92 (0.91)
	2-3	88.82 (12.60)	3.05 (0.74)
	Total	85.67 (15.35)	3.01 (0.78)

Memory task 1

The percentage accuracy data for the house, face and abstract image categories showed evidence of negative skew. Non-parametric tests were therefore used to analyse the data. To investigate whether participants' accuracy for each separate image category (house, face, abstract) was the same across each version of the task (1, 2, 3), a Kruskal-Wallis test was conducted. This suggested no significant differences in accuracy between task versions for house images (χ^2 (2) = 0.65, p = .721), face images (χ^2 (2) = 3.06, p = .216), or abstract images (χ^2 (2) = 2.13, p = .345). See table 3.2 for the mean rank values. This suggests that accuracy for each individual image category was not significantly different across the three versions of the memory task.

To compare percentage accuracy between the house, face and abstract images a Friedman test was conducted. This suggested there was a significant difference in percentage accuracy depending on the image category (χ^2 (2) = 18.76, p < .001). Follow-up analysis using Wilcoxon signed-rank tests with a Bonferroni correction was conducted with alpha set at p < .017. There was no significant difference in accuracy between the house (Mdn = 87.50) and abstract (Mdn= 87.50) images (Z = -0.79, p = .427). However, there was a significant difference between accuracy for face (Mdn = 93.75) and house (Mdn = 87.50) images (Z = -3.92, p < .001), with higher accuracy for face images than house images. There was also a significant difference between accuracy for face (Mdn= 93.75) and abstract (Mdn = 87.50) images (Z = -3.17, p = .002). This suggests that participant accuracy was higher for face images than house or abstract images.

To compare the *d'* between the image categories (repeated-measures factor) and task version (between-groups factor), a 3 (image category, house/face/abstract) x3 (task version, 1/2/3) mixed ANOVA was conducted on the data from memory task 1. There were no significant main effects of image category ($F(2,118) = 2.17$, $p = .119$) or task version ($F(2,59) = 1.04$, $p = .359$). There was also no significant interaction between image category and task version ($F(4,118) = 0.62$, $p = .651$). These results suggest that all of the image stimuli in each version of memory task 1 were equally memorable.

Memory task 2

The percentage accuracy data for the house, face and abstract image categories showed signs of negative skew. To investigate whether participants' accuracy for each separate image category (house, face, abstract) was the same across each version of the task (1, 2, 3), a Kruskal-Wallis test was conducted. This suggested no significant differences in accuracy between task versions for house images ($H(2) = 0.04$, $p = .978$), face images ($H(2) = 1.12$, $p = .571$) or abstract images ($H(2) = 0.47$, $p = .791$), mean rank values can be found in table 3.2. This suggests that the accuracy for each individual image category was not significantly different across the three versions of the memory task.

To compare percentage accuracy between the house, face and abstract images a Friedman test was conducted. This suggested that there were no significant differences in percentage accuracy depending on the image category (χ^2 (2) = 4.95, $p = .085$). To compare the *d'* between the image categories and task version, a 3 (image category, house/face/abstract) x3 (task version, 1/2/3) mixed ANOVA was conducted. Task version was the between-group factor and image category was the within-group factor. For memory test 2 this revealed no significant main effect of image category ($F(2,110) = 2.00$, $p = .140$) and no significant main effect of task version ($F(2,55) = 0.02$, $p = .981$). There was also no significant interaction between image category and task version ($F(4,110) = 1.36$, $p = .252$). This suggests that all of the image stimuli in each version of memory test 2 were also equally memorable.

Table 3.2.

Mean rank values from Kruskal-Wallis analysis, memory tasks 1 & 2

			Task version	
Memory task	Image category	1	2	3
A	House	33.31	28.87	28.00
	Face	28.00	29.37	36.68
	Abstract	27.31	31.82	35.25
B	House	28.90	29.92	29.76
	Face	32.48	27.47	28.13
	Abstract	28.28	28.44	31.63

Overall, task performance as measured by *d'* suggests that recognition memory was similar for abstract, face and house images in task 1 and 2 and across task versions 1, 2 and 3. Similarly, task performance as measured by percentage accuracy suggested similar accuracy for abstract, face and house images in task 2. In task 1, percentage accuracy was higher for face images, however, this was consistent across versions of task 1, 2 and 3. Due to the within-task consistency of these findings these images were deemed as suitable to use for the following joint attention studies.

Experiment 2.1 & 2.2[1]

3.3 Method

Participants

Participants were 31 children with an ASD diagnosis aged between 7 and 14 years old (Mean age in months = 127.94, SD = 20.48) and 33 typically developing children aged between 7 and 12 years old (Mean age in months = 122.97, SD = 16.35). There were four female participants per group.

Children were recruited from schools in central Scotland, following permissions from local education authorities and head teachers. Permission was granted from 5 councils and resulted in participant recruitment from 12 primary schools. These schools comprised mainstream schools, mainstream schools with specialist language and communication units and schools for children with special educational needs. Participants in the ASD group were identified by their school and recruited on the basis of their previous ASD diagnosis. This was further confirmed with an ADOS classification. One participant from the ASD group did not meet the criteria for an ADOS classification of autism. However, due to their previous

[1] The results of experiment 2.1 have been published as follows Little, G., Bonnar, L., Kelly, S., Lohan, K. S., & Rajendran, G. (2016). Gaze contingent joint attention with an avatar in children with and without ASD. Paper presented at 6th Joint IEEE International Conference on on Development and Learning and on Epigenetic Robotics 2016, Cergy-Pontoise, Paris, France.

community diagnosis and their score on the SCQ in the ‘high’ range (Charman et al., 2015) this participant’s data were retained in the study. One participant with ASD did not complete the tasks in full so was removed from further analyses (final ASD group N = 30, TD group N=33). Typically developing participants were recruited to match the ASD group based on the matching method used by Rajendran, Mitchell and Rickards (2005). Typically developing participants were individually matched to a participant from the ASD group on the basis of gender and then as closely as possible on both age and WASI FSIQ-4 score. Participant characteristics can be found in table 3.3. Independent samples t-tests were conducted to test for any differences between the groups. There were no significant differences in age between the groups at experiment 2.1 ($t(61) = 1.01$, $p = .217$) and experiment 2.2 ($t(61) = .998$, $p = .246$) and no significant group differences in full scale IQ (FSIQ-4) ($t(61) = -.725$, $p = .124$). Of the children whose parents returned an SCQ questionnaire (ASD group N=22, TD group N=25), those in the ASD group displayed significantly higher SCQ scores than the TD group ($t(45) = 10.91$, $p < .001$, $d = 3.25$).

Table 3.3.

Participant characteristics, study 2

	ASD (N= 30)	TD (N=33)
Age in months at exp. 2.1	128.16 (20.79)	122.97 (16.35)
Age in months at exp. 2.2	128.87 (20.82)	124.18 (16.36)
FSIQ-4	87.10 (13.43)	89.27 (10.26)
SCQ score	24.64 (6.43) * [a]	6.12 (5.19) * [b]
ADOS total score	11.33 (3.66)	N/A

* p <.001

[a] Total SCQ returns, N= 22

[b] Total SCQ returns, N= 25

All participants had normal or corrected to normal vision (e.g. glasses) and no known visual deficits. The children's parents provided written informed consent for their child to take part in the study and the children themselves provided verbal assent at each time of testing. The study received ethical approval from the University of Strathclyde Ethics Committee.

Materials

Wechsler Abbreviated Scale of Intelligence-II

Participants completed all four subsets of the Wechsler Abbreviated Scale of Intelligence-II (WASI-II, Wechsler & Hsiao-Pin, 2011). These comprise the block design, vocabulary, matrix reasoning, and similarities subtests. For these subtests, participants are asked to arrange blocks according to a series of illustrated patterns, define words, complete a pattern using deductive reasoning and state the similarities between two given words. This was used to compute a composite score of an estimate of intellectual functioning in both verbal comprehension and perceptual reasoning for each participant. It also provided a composite, full scale IQ score for each participant. This score was used to estimate their general intellectual ability.

Corsi blocks tapping task

A computer based version of the Corsi blocks tapping task (Kessles, van Zandvoort, Postma, Kappelle & de Haan 2000) was used as a measure of visuo-spatial, short-term working memory. This was run on a Dell latitude E6510 laptop with a 15” screen, using the Psychology Experiment Building Language (PEBL), version 0.13. The computerised Corsi blocks task is based on the original Corsi blocks tapping task (Corsi, 1972). In the original Corsi blocks task, 9 blocks are arranged on a board and the experimenter taps the blocks with a pencil in a series of increasingly difficult sequences. The participant is asked to replicate each sequence by pointing to the blocks in the same order. In the computerised version of this task, participants are presented with 9 blue squares on a black screen. The participant observes as a sequence of the squares are lit up in yellow and they must then replicate the sequence by clicking on the squares in the same sequence order. The sequences begin with two squares being lit up and progressively increase to a sequence using all nine squares. Two trials of the same sequence length are presented. The number of correct sequences and the longest sequence remembered are recorded.

Autism Diagnostic Observation Schedule

Participants with a previous ASD diagnosis completed the Autism Diagnostic Observation Schedule, second edition (ADOS-2; Lord, Rutter et al., 2011) for confirmation of their diagnosis. This is a standardised measure of social communication, interaction, play, imagination and restrictive and repetitive behaviours. It is widely perceived to be the ‘gold standard’ observational assessment measure of ASD (Kanne, Randolph & Farmer, 2008). The ADOS consists of 5 possible modules for its administration. The children were tested using ADOS module 3. This was designed for use with verbally fluent children under the age of 16yrs old and consists of 14 structured and semi-structured activities. These include: a construction task where participants are asked to use shapes to make a pattern on a grid; make believe and joint interactive play, where participants are given a selection of action figures and toys to play with after which the examiner then joins in the play; a demonstration task where the participant is asked to demonstrate a routine activity such as teeth brushing; description of a picture, where the participant is shown a picture or selection of pictures to comment on; telling a story from a book, where the participant is shown a picture book and asked to tell some of the story; cartoons, where the participant is shown a story with cartoons which they then have to re-tell to the examiner; creating a story, where participants are asked to create a story with 5 random objects. Throughout the ADOS assessment, participants are also asked questions about relationships, social difficulties and annoyances, loneliness and emotions. The ADOS also includes a break where the participant is given appropriate materials to occupy their time with. These activities are designed to elicit behaviours related to a diagnosis of ASD and provide a sample of the participant's language, communication, social interaction, play and restricted and/or repetitive behaviours for coding. This is used to generate an algorithm score, which is compared to a cut-off score. The cut-off score provides one of three classifications: autism, autism-spectrum, or non-autism. The classifications of autism and autism spectrum differ in their severity with a classification of autism suggesting more pronounced symptoms.

The primary researcher completed training in the administration and coding of each module of the ADOS to clinical and researcher reliability in December 2013. ADOS administrations were conducted by the primary researcher and videotaped to allow for double coding. A random sample of six ADOS administrations were selected for double coding by another coder who had also received training in the ADOS to clinical and researcher reliability. Agreement between the researcher and double coder on ADOS comparison scores and autism diagnoses was 100%. Exact agreement for overall individual algorithm items was 88%. When separated into 'Social Affect' (SA) and 'Restrictive Repetitive Behaviours' (RRB), algorithm item agreement was 83.33% and 100% respectively. This is above the expected ≥80% level of agreement for ADOS reliability.

Stimuli

Avatar's physical appearance

The avatar for this experiment was created and rendered using open source 3D graphics software 'Blender' (version 2.6, blender.org). Only the upper body (shoulders, neck, head and face) of the character was visible. The character was named "Danny" and was designed to be male, childlike and cartoonish in appearance, portraying a neutral facial expression. Two different versions of Danny were created to compare different hair textures and determine any preference between the two. These varied only in the texture and colour of their hair. Both versions can be seen in figure 3.1. These characters were compared and rated by 25 children aged between 5 and 12 yrs. (10 males and 15 females, mean age = 9.16 yrs. SD = 1.75). For the ratings, the children were given a sheet of paper with images of both versions of Danny side by side. They were asked to imagine they were going to work together with one of the characters in a computer game to win points. The children were then asked to draw a tick or a cross next to the character they would prefer to work with. They were also asked to write what age they thought each of the characters might be. There was no clear preference for one version of the character over another, 13 out of the 25 children preferred the second version of Danny. On average, the children perceived the first version of the character to be 9.7 yrs. old

(SD = 1.5, range = 7 yrs. - 13 yrs.) and the second version to be 9.5 yrs. old (SD = 1.8, range = 7 yrs. – 12 yrs.). This suggests that the objective to create a childlike character was successful. The second version of Danny was used for the subsequent experimental tasks.

The avatar was animated to make a head turn and eye movement towards images appearing on his left and right side. The timing and movement of his head turn and eye movements were based on video footage of a person facing forward and looking at two objects at eye level, directly either side of them. The avatar's eyes moved faster than his head and rotated independently, peering beyond the rotation of the head. The avatars head turned 36° left or right and his eyes rotated 47°. The timing of the full transition from the character facing forward to completing the look to either side was 640ms. Pfeiffer et al. (2012) suggest that gaze following responses of a virtual agent that were between 400ms-800ms were perceived as the most natural and human-like. The animation was presented at 25 frames per second.

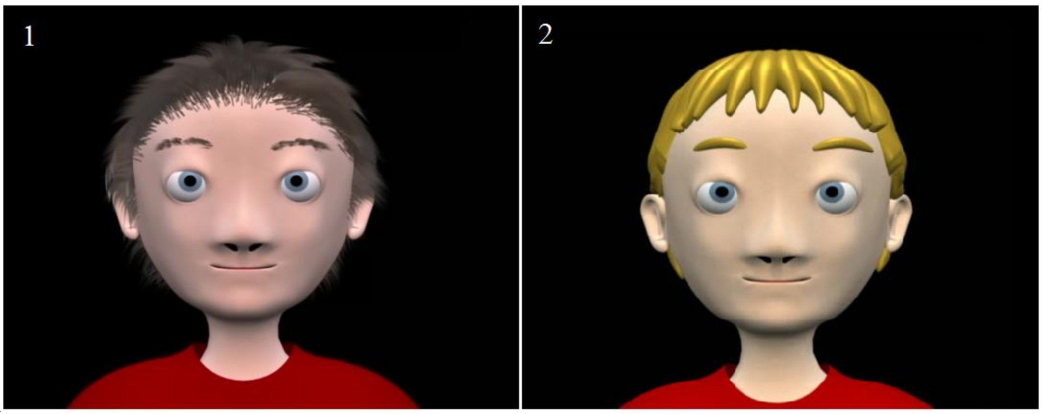

Figure 3.1. Avatar version 1 and 2

Image stimuli

The face, house and abstract images from the pilot memory tasks A and B were used as image stimuli for this study. Images from memory task 1 were used for joint attention experiment 2.1 and images from memory task 2 were used for joint attention experiment 2.2. Each joint attention task comprised a total of 144 images. These consisted of 48 house images, 48 abstract images and 48 face images (24 male faces, 24 female faces).

The joint attention tasks

Joint attention experiment 2.1

In joint attention experiment 2.1 participants were presented with the animation of the avatar. The avatar was presented on a black background, in the centre of the screen and measured 6.9° by 8.7°. During the experimental trials, the avatar was flanked by two rectangular placeholders in which the image stimuli (faces, houses or abstract images) appeared. The placeholders were black with a white border and were displayed 7.8° from the centre of the screen to the left and right. The placeholders and image stimuli measured 5.6° by 6.9°.

There were two joint attention conditions in the present task, a responding to joint attention (RJA) condition and an initiating joint attention (IJA) condition. These conditions differed in the way that the participant chose, or was directed to the target images they were asked to remember. Both conditions comprised 4 learning phases, each followed by test phases.

Experiment 2.1 learning phase

RJA condition

In the RJA condition, participants were instructed to look at the avatar, then follow his gaze to one of the placeholders and remember the image that appeared. In each block, the avatar made an equal number of looks to the left and right placeholders and the order of his direction of gaze was randomised. The images the avatar directed the participant to view were the target images. The images in the opposite placeholder were non-target images; these were presented but not designated for viewing and memorising. Target and non-target images presented in a single trial were always unique images from the same image category. The duration of the head turn and gaze towards the placeholder was 640ms. To help control looking time to the images, the images were only presented in the placeholders when participants had fixated on the target placeholder for 200ms. This was also to ensure that each participant was looking at the correct placeholder when the images appeared. The images were presented for 1000ms before disappearing. When the image disappeared, the avatar held his gaze to the empty placeholder for 400ms before returning to look back to the centre, towards the participant. Participants were instructed at this point to look back at the avatar to complete the trial. Between each trial the avatar disappeared from the screen and a fixation point was presented. Before the next trial could commence there was a 860ms pause.

IJA condition

In the initiating joint attention condition (IJA) participants were asked to look at the avatar and then choose one placeholder to look at. When participants had fixated on one of the placeholders for 200ms, eye tracker feedback allowed the avatar to follow their gaze to the same placeholder. The images subsequently appeared in both placeholders for 1000ms. In this condition, the target image was the image presented in the placeholder that the participant chose to look at first, and the non-target image was the image presented in the opposite placeholder. When the images disappeared, the avatar again held his gaze to the empty placeholder for a further 400ms. This was to ensure that participants knew that the avatar had followed their gaze. Following this, the avatar returned his gaze to the centre. Participants again were asked to return their gaze to the avatar to complete the trial. Between each trial the avatar disappeared from the screen and a fixation point was presented. There was a pause of at least 860ms before the next trial could begin. Figures 3.2 and 3.3 show examples of an RJA trial and an IJA trial.

In both the RJA and IJA conditions, participants completed two blocks of 12 learning trials where they were asked to study the target images and remember as many as they could for later. Participants completed a total of 4 blocks in the learning phase with a total of 48 learning trials. The order in which the RJA and IJA blocks were presented was counterbalanced across participants. Each block consisted of 4 trials of face, house and abstract stimuli. The presentation of images as targets, non-targets, and novel images was also counterbalanced across participants with the image presentation being randomised.

Test phase

The test phase was completed after each learning phase. This comprised a random presentation of 24 familiar images (12 of which had been target images and 12 non-target images), along with 12 novel images that had not previously been presented. These 36 images were sequentially presented and participants indicated with a button press whether they recognised the image or not. The response buttons were clearly marked with large stickers showing a ‘Y’ for remember and ‘N’ for do not remember, and were counterbalanced across participants.

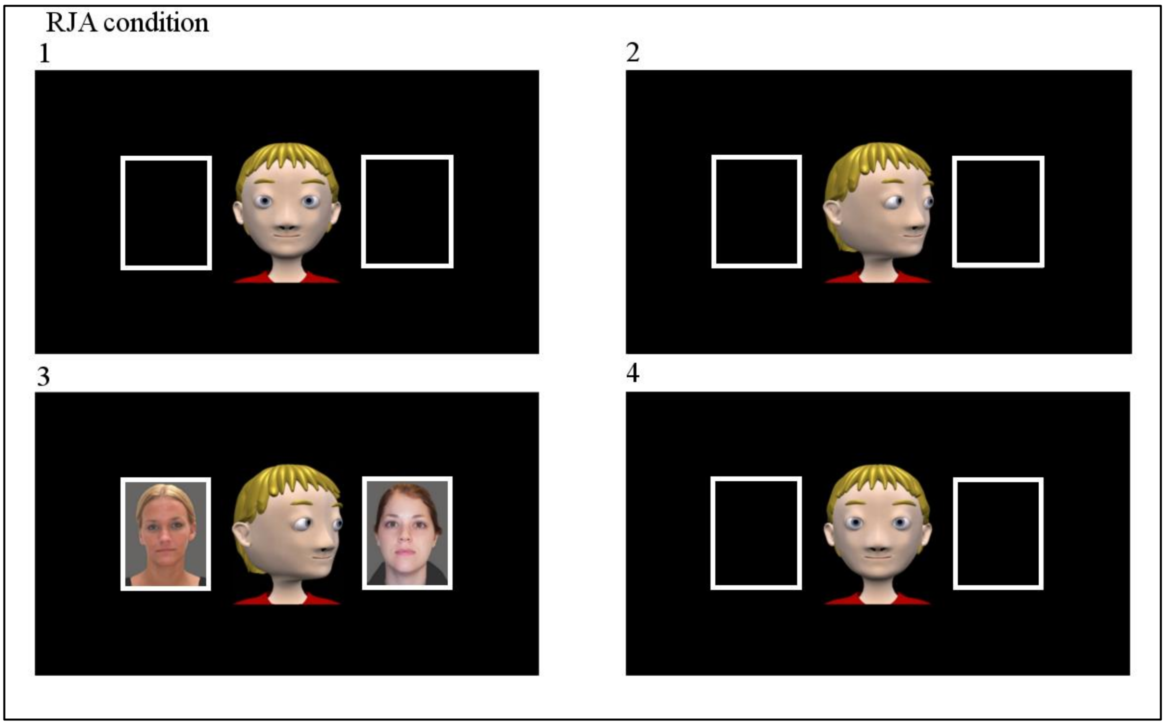

Figure 3.2. Presentation of an RJA trial. 1. Initiation look, the avatar gazes forward for 300ms. 2. Reference look- the avatar turns to look at placeholder, head turn duration: 640ms. 3. When participant makes fixation (≥200ms) on the correct placeholder images appear for 1000ms, when images disappear the avatar remains fixated on empty placeholder for 400ms. 4. Sharing look, the avatar returns his gaze to the participant for 860ms.

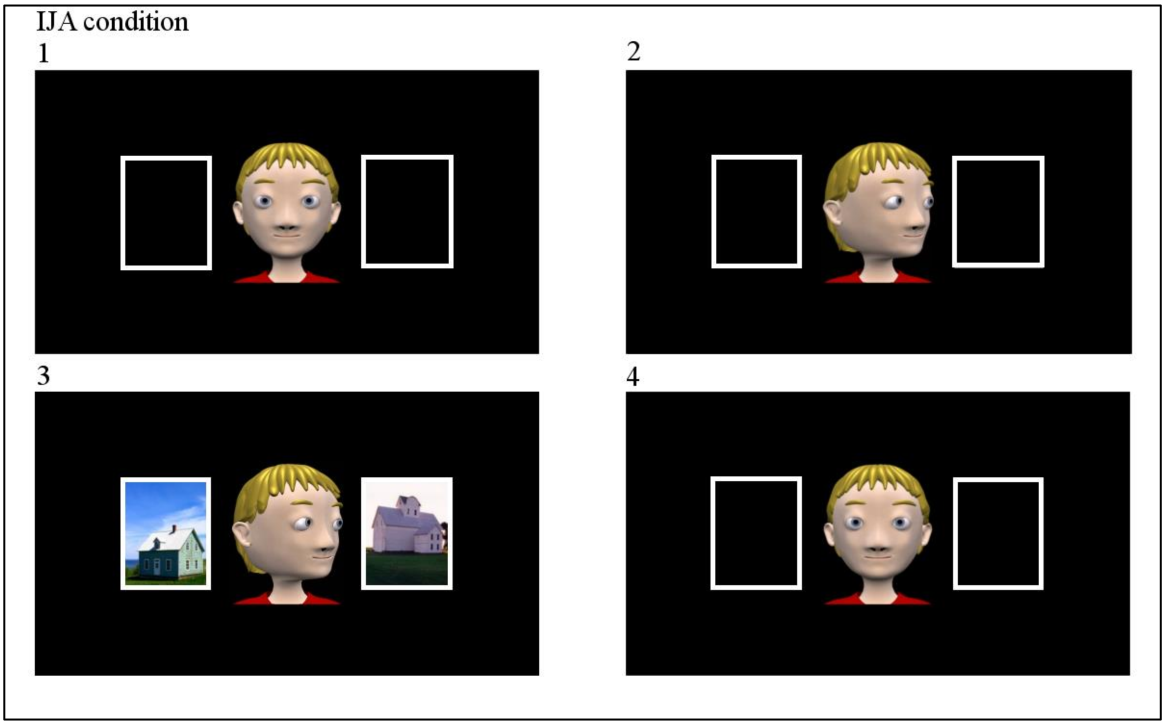

Figure 3.3. Presentation of an IJA trial. 1. Initiation look, the avatar gazes forward waiting for participant's reference look. 2. Participant chooses placeholder by making reference look to one placeholder. After participant fixation of ≥200ms on one placeholder, the avatar makes head turn to the same placeholder. Duration of head turn: 640ms 3. Images appear for 1000ms, when images disappear the avatar remains fixated on empty placeholder for 400ms. 4. Sharing look, the avatar returns his gaze to the participant for 860ms.

Joint attention experiment 2.2

Joint attention experiment 2.2 was very similar to joint attention experiment 2.1, except there was no RJA condition. This was with the aim to further explore IJA and investigate any differences in the effect of the participant's gaze initiation being followed (successful IJA) and ignored (not successful IJA). Each of the 4 blocks in experiment 2.2 consisted of IJA trials. These trials were similar to the IJA trials outlined in experiment 2.1 except for half of the trials the avatar followed the participant's gaze (gaze-followed condition) and for half of the trials he looked at the opposite placeholder (gaze-ignored condition). The order of whether the participant's gaze was followed or ignored was randomised. The test phase of this task was the same as detailed above for joint attention experiment 2.1.

Due to a programming error in experiment 2.2, twenty-two participants in the ASD group were presented with an unbalanced number of abstract, face and house target stimuli for the gaze-followed and gaze-ignored conditions. Although all participants saw the same total number of abstract, face and house images, these should have been presented 8 times each per JA condition. See table 3.4 for details on the presentation of the stimuli due to this error. This programming issue was resolved for the remaining ASD participants and all of the TD participants who were presented with an equal number of abstract, face and house images per JA condition.

Table 3.4

Number of images shown due to programming error (ASD group, N=22)

JA condition	Image type	Minimum	Maximum	Mean (SD)
Gaze followed	Abstract	5	10	8.23 (1.39)
	Face	3	9	7.29 (1.72)
	House	6	12	8.47 (1.62)
Gaze ignored	Abstract	6	11	7.76 (1.39)
	Face	7	13	8.71 (1.39)
	House	4	10	7.53 (1.62)

Hardware and software

The experimental programme was created and run on E-prime with E-prime extensions for Tobii (E-prime). The experiment was displayed on a Dell latitude E6510 laptop with a 15.5" screen. The screen resolution was 1366/768 with a refresh rate of 60Hz. Eye movements were tracked using a Tobii X260 eye tracking device (Tobii, Stockholm, Sweden) which recorded eye movements binocularly at 60Hz with a spatial resolution of 0.4°

Procedure

The procedure for this study was split into separate experimental sessions. All children completed the WASI-II in one session and the experimental joint attention tasks 2.1 and 2.2 in two separate experimental sessions on different days. The participants with autism completed an additional, separate, hour-long session in which the ADOS was conducted. All participants completed the ADOS and/or the WASI-II sessions before taking part in the joint attention tasks. For all of these sessions, participants were tested individually in a quiet room in their school.

Each participant first completed the WASI-II session. This session took approximately 30-40 minutes per participant. The ADOS sessions were videotaped for reference to aid with coding and allow for double coding. Each ADOS session lasted between 40 minutes – 1 hour approximately.

In the penultimate session, participants completed the computer based Corsi blocks task and joint attention experiment 2.1. For the Corsi blocks task participants sat in front of the laptop and were asked to look at the 9 blue squares on the screen, observe them turn yellow in sequence and copy the sequences shown by using the computer mouse to click on the squares to turn them yellow. Participants were given two practice trials with a sequence of two squares before the experimental trials began. The Corsi blocks task took approximately 5 minutes to complete.

Participants then began joint attention experiment 2.1. Before the task began, participants were presented with a screen showing the avatar flanked by the empty placeholders, above the avatar were the words “Hi! I’m Danny”. Participants were introduced to the avatar and told that they would be playing a remembering game with him. The two boxes (placeholders) were pointed out and it was explained that pictures would appear in the boxes during each trial. They were then told they would have to try to remember one of the pictures from each pair that appeared. They were instructed that they would take it in turns with Danny to choose one of the boxes to look at and they should try to remember the picture that appears in their or Danny’s chosen box for later.

A chin-rest was used to maintain participants’ fixation at 60cm from the eye tracker, which was positioned at the bottom of the laptop screen. This setup was within the manufacturer recommended viewing distance of 60-65cm for best eye tracking performance (Tobii, 2014). A calibration procedure then took place where participants were asked to follow a red dot around the screen with their eyes. This procedure was repeated until a good calibration was achieved and the joint attention task could begin.

At the beginning of the first RJA and IJA blocks, participants were given a minimum of 4 practice trials where they could practice looking at the boxes with Danny. These practice trials could be repeated as many times as necessary, until the participant was comfortable with the trial procedure. The images shown in the placeholders for the practice trials were images of fruit and vegetables. For the RJA practice trials participants were instructed to look at Danny, wait for him to choose a box to look at and to look at the same box as him. They were also instructed to look back to Danny at the end of each trial. For the IJA practice trials participants were instructed to look at Danny and then decide which box to look at. They were told to look at only one box and then to look back to Danny at the end of the trial.

For the RJA learning phase blocks, it was explained that it was Danny's turn to choose which box to look at and which picture to try to remember for each trial. The following written instructions were presented on the screen and read aloud by the experimenter "It's Danny's turn to choose which box to look at and which picture to remember. Look at Danny. Danny will then look at one of the boxes. Study the picture that appears in the box Danny looks at and try to remember it for later". For IJA learning phase blocks, it was explained that it was the participant's turn to choose which box to look at and which picture to try to remember for each trial. The instructions, "It's your turn to choose which box to look at. Look at Danny and then look at your chosen box. Danny will look at the picture with you. Try to remember the picture for later." appeared on the screen and were read aloud by the experimenter

Immediately after each block, the test phase was explained to participants. Participants were asked to press the 'Y' key if they recognised the image from before and the 'N' key if they did not recognise the image from before. Participants were reminded of this instruction before the beginning of each test phase. If the examiner was unsure of the participants' understanding, they asked the participant to tell them which button to press if they remembered/did not remember the picture. Participants were then presented with the recognition memory test. In total, this session took approximately 30 minutes.

In the final session, participants completed joint attention experiment 2.2. The instructions given and procedure for each block was similar for the IJA blocks in experiment 2.1. Except, in experiment 2.2, participants were explicitly told that this time sometimes Danny would look at the same picture as them and sometimes he would look at the other picture and that they should to try to remember the pictures that appeared in their chosen box, regardless of where Danny looked. The procedure and instructions for each testing phase was the same as in experiment 2.1. This session lasted approximately 30 minutes per participant.

For each participant, all four sessions were completed within approximately 4 months at the most convenient times for the participants and their school. The joint attention tasks were completed with at least one week between experiments 2.1 and 2.2. The children were given an SCQ questionnaire to deliver to their parents at the beginning of their participation. These were returned to the child's school in sealed envelopes and collected by the researcher at the end of the schools participation in the study. Table 3.5 shows a summary of the study procedure.

Table 3.5.

Summary of study 2 procedure

Experimental session	ASD group	TD matched controls
1	• WASI-II *(block design, vocabulary, matrix reasoning, similarities)*	• WASI-II *(block design, vocabulary, matrix reasoning, similarities)*
2	• ADOS	• Corsi blocks • Experiment 2.1
3	• Corsi blocks • Experiment 2.1	• Experiment 2.2
4	• Experiment 2.2	
	• SCQ questionnaire collected	• SCQ questionnaire collected

3.4 Results

Corsi blocks task

The total number of correct trials, total score, block span, and memory span were recorded. Block span is a capacity measure representing the length of the last correctly replicated sequence. Total score was calculated by multiplying the block span and total number of correct trials. This provides a more sensitive measure than block span (Kessels, et al., 2000). Memory span was calculated by adding the starting length of trials (2 blocks) to the total number of correct trials and then dividing this by the number of trials per sequence length (2 trials). Mean Corsi block scores and standard deviations are shown in table 3.6.

Table 3.6.

Corsi blocks scores, study 2

	ASD (N= 30)	TD (N=33)
Total score	29.50 (19.83)	33.55 (10.92)
Total correct trials	5.80 (2.37)	6.67 (1.45)
Block span	4.57 (1.43)	4.81 (0.84)
Memory span	3.90 (1.18)	4.33 (0.73)

Independent samples t-tests revealed no significant differences between the groups' total scores (t(44.15) = -.989, p = .328), block span (t(46.14) = -.839, p = .406), number of correct trials (t(47.16) = -1.73, p = .090) or memory span (t(47.16)

= -1.73, *p* = .090). Levene's test indicated unequal variance for all four measures (*F* = 76.22, *p* = .015), (*F* = 7.33, *p* = .009), (*F* = 8.56, *p* = .005) and (*F* = 5.61, *p* = .005) respectively) so degrees of freedom were adjusted from 61 accordingly. Overall, these results suggest comparable performance on the Corsi blocks task across the ASD and TD groups.

Joint attention task results

The total number of target hits (correct "yes" responses to a target image) and false alarms (incorrect "yes" responses to a novel image) were calculated for each JA condition (RJA/IJA) and image type (abstract, face, house) per JA condition. The loglinear approach was again applied to determine hit and false alarm rates for the *d'* calculation (see section 3.2.2 for a description). Although *d'* was the main variable of interest, a beta index (β) was also calculated to provide a measure of response bias for 'yes' or 'no' responses. This was calculated by squaring the z-score for the false alarm rate and subtracting the square root of z-scores for the hit rates, this result was then divided by two to provide the beta value (Stanislaw & Todorov, 1999).

One participant from the ASD group did not complete either of the joint attention experiments due to unsuccessful eye tracker calibration. Furthermore, participants who scored at or below chance level for any of the overall JA conditions (*d'* of ≤ 0) were removed from the following analyses. These participants were the lowest scorers who may not have been completing the tasks correctly. Memory test responses and gaze data for experiments 2.1 and 2.2 were inspected for any abnormalities and outliers. Where appropriate, transformations were applied. Initial screening of the memory test and gaze data revealed skew in some experimental conditions that was not eliminated by transformations. Parametric tests are considered to be robust to violations of normal distribution (e.g. Clark-Carter, 1997) so parametric analyses are reported here to allow interaction effects to be investigated. Nevertheless, precautionary non-parametric tests were also conducted, results of which were mostly consistent with the findings from the parametric analyses. Where these were not consistent, this is reported.

Joint attention experiment 2.1

5 ASD participants (3 female) and 4 TD participants (total remaining ASD: N = 24, TD: N = 29) were removed from experiment 2.1 analysis for chance performance (*d'* of ≤ 0). To compare group performance, ASD participants who scored above chance level in the RJA and IJA conditions were compared with their TD matches. Where a TD match was removed from the analysis due to overall chance performance they were replaced with their best remaining match. This led to 3 ASD participants being matched with the closest remaining match. An independent samples t-test suggested no significant differences in age ($t(46) = .246$, $p = .807$) or IQ ($t(46) = -.150$, $p = .881$) between the groups. Of the participants who returned SCQ questionnaires, scores were significantly different between ASD and TD groups ($t(35) = 10.27$, $p < .001$, $d = 3.47$). No differences in total scores ($t(34.54) = -0.19$, $p = .850$) or memory span ($t(38.49) = -0.79$, $p = .433$) for the Corsi blocks tasks were found between the groups. Levene's test indicated unequal variance for the corsi block data so degrees of freedom were adjusted accordingly. Table 3.7 shows participants mean age, IQ and SCQ scores and ADOS and Corsi block scores for both groups.

Table 3.7.

Participant characteristics, study 2, experiment 2.1

	ASD (N=24)	TD (N=24)
FSIQ-4	90.54 (12.21)	91.04 (10.82)
Age in months	128.63 (21.23)	127.33 (14.54)
SCQ score	25.12 (6.83)***[a]	6.10 (4.34)***[b]
ADOS total score	11.13 (3.21)	N/A
Corsi total score	32.04 (20.93)	32.96 (10.86)
Corsi memory span	4.08 (1.2)	4.31 (0.75)

*** p <.001
[a]17 SCQ questionnaires returned
[b]20 SCQ questionnaires returned

Effect of JA, experiment 2.1.

Table 3.8 shows the, *d'* and β values of the ASD and TD groups' responses in the RJA and IJA conditions.

Table 3.8.

d' and β values, experiment 2.1

	ASD group (N=24)		TD group (N=24)	
	d'	β	*d'*	β
RJA	1.01 (0.57)	-0.37 (0.62)	1.83 (0.77)	-0.51 (0.77)
IJA	0.92 (0.56)	-0.35 (0.63)	1.74 (0.87)	-0.59 (0.81)

A 2 (JA condition, RJA/IJA) × 2 (group, ASD/TD) mixed ANOVA on the *d'* scores, with 'group' as the between groups factor revealed no significant main effect of JA condition ($F(1,46) = 1.48$, $p = .229$) and no interaction between JA condition and group $F(1,46) = .000$, $p = .993$). There was a significant main effect of group ($F(1,46) = 18.63$, $p < .001$, $\eta_p^2 = .29$), suggesting that ASD participants demonstrated significantly poorer memory overall than TD participants.

The same analysis for beta values revealed no significant main effect of JA condition ($F(1,46) = .250$, $p = .619$) or group ($F(1,46) = .968$, $p = .330$), and no interaction between JA condition and group $F(1,46) = .523$, $p = .473$). This suggests no difference in response bias between the groups and JA conditions.

Effect of image type, experiment 2.1

Many of the participants included in the overall JA analysis performed at, or below, chance level (ASD N = 16, TD N = 2) for at least one of the image type conditions (1 ASD participant scored at chance level for the abstract images, 6 ASD and 2 TD participants scored at or below chance for the face images and 3 ASD participants scored at chance for the house images in the RJA condition. In the IJA condition, 3 ASD participants scored at or below chance level for the abstract images and 9 scored at chance for the face images). In the interest of a true reflection of the performance of the participants who completed the task at above chance level for both JA conditions overall, these participants were included in the analysis. *d'* and β means and standard deviations can be found in table 3.9.

Table 3.9.

d' and β means and standard deviations for each JA condition and image type, experiment 2.1

		ASD group (N=24)		TD group (N=24)	
		d'	β	*d'*	β
RJA	Abstract	1.27 (0.73)	-0.17 (0.68)	2.00 (0.85)	-0.32 (0.68)
	Face	0.62 (0.56)	-0.15 (0.46)	1.34 (0.73)	-0.19 (0.78)
	House	1.00 (0.72)	-0.32 (0.55)	1.76 (0.69)	-0.35 (0.77)
IJA	Abstract	0.99 (0.71)	-0.36 (0.50)	1.61 (0.75)	-0.41 (0.61)
	Face	0.54 (0.68)	-0.18 (0.44)	1.52 (0.77)	-0.34 (0.73)
	House	1.06 (0.54)	-0.10 (0.67)	1.60 (0.90)	-0.48 (0.53)

Data for the house images in the IJA condition violated assumptions of homogeneity of variance ($F(1,46) = 11.35$, $p = .002$) and demonstrated positive skew which was not eliminated by transformations, the original data were therefore used for analysis. A mixed 2 (JA condition, RJA/IJA) × 2 (group, ASD/TD) × 3 (image type, abstract/face/house) ANOVA with 'group' as the between groups factor revealed no significant main effect of JA condition ($F(1,46) = 3.19$, $p = .081$). No significant interaction between JA condition and group ($F(1,46) = .024$, $p = .877$) and no significant interaction between image type and group ($F(2,92) = .799$, $p = .453$) was found.

A significant main effect of group ($F(1,46) = 22.66$, $p < .001$, $\eta_p^2 = .33$) was revealed, with the TD group outperforming the ASD group for each image type and attention condition. There was also a significant main effect of image type ($F(2,92) =$

15.57, $p < .001$, $\eta_p^2 = .25$). Bonferroni corrected pairwise comparisons suggested no significant differences between *d'* scores for house and abstract images ($p = .680$), however, *d'* scores were significantly lower for face images than house images ($p < .001$) and abstract images ($p < .001$).

A significant interaction between JA condition and image type was also revealed ($F(2,92) = 3.59$, $p = .031$, $\eta_p^2 = .07$). To further investigate this interaction two separate repeated-measures ANOVAs were conducted, one for *d'* data from the RJA condition and one for *d'* data from the IJA condition. The ANOVA for the RJA condition revealed a significant main effect of image type ($F(2,92) = 17.54$, $p < .001$, $\eta_p^2 = .28$) and group ($F(1,46) = 20.59$, $p < .001$, $\eta_p^2 = .31$). There was no significant interaction between image type and group ($F(2,92) = .010$, $p = .990$). Bonferroni corrected pairwise comparisons suggested no significant differences between *d'* scores for abstract and house images ($p = .146$), but significantly lower *d'* for face images compared to abstract ($p < .001$) and house images ($p < .001$). The ANOVA for the IJA condition also revealed a significant main effect of image type ($F(2,92) = 3.85$, $p = .025$, $\eta_p^2 = .08$) and group ($F(1,46) = 18.24$, $p < .001$, $\eta_p^2 = .28$) and no significant interaction between image type and group ($F(2,92) = 1.98$ $p = .144$). Bonferroni corrected pairwise comparisons suggested no significant differences in *d'* scores between abstract and house images ($p = 1.00$), the difference in *d'* for face images compared to abstract ($p = .051$) and house images ($p = .053$) approached significance with face images eliciting lower *d'* scores. It must be noted here that nonparametric Wilcoxon signed rank test suggested that the difference between *d*' scores for face and abstract (Z = -2.30, $p = .022$) and face and house (Z = -2.32, $p =$

.020) images were statistically significantly, all other nonparametric results were consistent with the reported parametric analysis.

Bonferroni corrected paired-samples t-tests with alpha set at $p < .017$ were also conducted to compare each image type at each joint attention condition. This revealed no significant differences in *d'* scores between the RJA and IJA conditions for face images ($t(47) = -.514$, $p = .610$) or house images ($t(47) = .506$, $p = .615$). The difference in *d'* scores for the abstract images between the IJA and RJA conditions reached significance ($t(47) = 3.18$, $p = .003$, $d = 0.46$) with higher scores in the RJA than the IJA condition.

Non-target images, experiment 2.1

The number of non-target images eliciting a "yes" response was expected to be significantly lower than the number of target images remembered. The mean number of non-target "yes" responses for each JA condition and image type are presented in table 3.10.

Table 3.10.

Non-target 'yes' responses, experiment 2.1

JA condition	Image Type	ASD	TD
RJA	Abstract	3.33 (2.41)	1.54 (1.56)
	Face	3.42 (1.86)	2.04 (1.65)
	House	2.87 (2.07)	1.58 (1.77)
IJA	Abstract	3.83 (1.97)	1.71 (1.68)
	Face	3.50 (1.95)	3.33 (2.06)
	House	3.58 (2.16)	2.21 (1.74)

Shapiro-Wilk tests suggested the data from some conditions was non-normal, it also showed signs of positive skew. Transformations of the data did not reduce the skew so the original data were used for analysis. Data from the RJA abstract condition violated assumptions of homogeneity of variance ($F(1,46) = 5.52$, $p = .023$). Again, due to the equal group sizes and the robustness of analysis of variance, a mixed ANOVA was still used to analyse the data. A 2 (group: ASD, TD) × 2 (JA condition: RJA, IJA) × 2 (Image category: target, non-target) × 3 (image type: abstract, face, house) mixed ANOVA with group as the between-groups factor, revealed a significant main effect of image category ($F(1,46) = 127.37$ $p < .001$, $\eta_p^2 = .74$) and no significant main effect of group ($F(1,46)=.493$, $p = .493$), JA condition ($F(1,46) = 2.55$, $p = .117$) or image type ($F(2,92) = .374$, $p = .689$). The interaction between image category and group ($F(1,46) = 29.16$ $p < .001$, $\eta_p^2 =.39$) was significant with Bonferroni corrected pairwise comparisons suggesting significantly more target hits than non-target hits for both the ASD ($p < .001$) and TD group ($p < .001$). Bonferroni comparisons also suggested significantly more target hits for the TD group ($p < .001$) and significantly more non-target hits for the ASD group ($p <.001$). The interaction between image category and JA condition was also significant ($F(1,46) = 6.83$ $p = .012$, $\eta_p^2 =.13$). Bonferroni pairwise comparisons suggested significantly more target hits than non-target hits in both the RJA ($p < .001$) and IJA conditions ($p <.001$). No significant difference in the number of target hits was found between the RJA and IJA conditions ($p = .241$). However, significantly more non-target hits were found for the IJA condition than the RJA condition ($p = .008$). The interaction between image category and image type was also significant ($F(2,92) = 9.27$ $p < .001$, $\eta_p^2 = .17$), Bonferroni corrected pairwise comparisons suggested significantly more target hits than non-target hits for each image type (all $p < .001$). No significant difference in the number of non-target hits was found between the image type conditions (all $p > .1$). For target hits the difference between face and abstract hits approached significance ($p = .051$) with more hits for abstract target images, no other comparisons approached significance ($p > .1$).

Gaze data analysis, experiment 2.1

The gaze data were first visually inspected for anomalies. This led to the removal of the entire data set for one ASD participant due to eye tracker error leading to missing trials for that participant. Gaze data were analysed for the period that the target image was presented on the screen. Firstly, ‘on-screen percentage viewing time’ was calculated for each participant. This represented the percentage of time participants point of gaze was detected anywhere on the screen during the ‘show target’ period of all trials. Total viewing times to each area of interest (AOI) were also calculated for the show target period. The AOIs for analysis were the target and the non-target image placeholders and the avatar, these AOIs included a margin of 1° around their borders. Viewing time within each AOI was defined as the total amount of time the eye tracker detected the participant’s point of gaze within its boundary. Total viewing times were calculated as a straightforward analogue of the total processing time the participant had on each AOI during the critical show target time period. Inspection of this data suggested two outliers in the ASD group. One participant demonstrated a reduced on-screen percentage (< 75%) and the other participant demonstrated limited time spent looking at the task AOIs despite an on-screen viewing time similar to the rest of the ASD group. These participants were removed from the gaze data analysis (final N for gaze data analysis: ASD = 21, TD = 24). The mean ‘on-screen’ percentages for each group are shown in table 3.11 and mean total viewing times (ms) to the AOIs for the show-target period are presented in table 3.12.

Table 3.11.

Percentage 'On-screen' performance, experiment 2.1

Group	On-screen % RJA	On-screen % IJA
ASD (N=21)	93.63 (5.82)	93.23 (6.83)
TD (N=24)	99.68 (0.23)	98.21 (0.19)

Table 3.12.

Average total viewing times (ms) for each AOI and JA condition per group, experiment 2.1

JA condition	AOI	ASD (N=21)	TD (N=24)
RJA	Target image	16032 (3526)	20040 (2799)
	Non-target image	2743 (1968)	1413 (1414)
	Avatar	1935 (1190)	500 (465)
IJA	Target image	11330 (3396)	15427 (3750)
	Non-target image	4986 (2612)	3494 (2779)
	Avatar	4201 (2487)	2576 (1428)

On screen percentage viewing time, experiment 2.1

The on screen percentage data showed evidence of negative skew. A square-root transformation completely eliminated this skew so the transformed data were used for the analysis. Independent samples *t*-tests were conducted to compare on-screen percentage viewing time between the groups, Levene's test indicated violation of the assumption of equality of variance therefore degrees of freedom were adjusted accordingly. Significant differences in on-screen percentage between the ASD and TD groups for the RJA condition ($t(20.29) = 5.90$, $p < .001$, $d = 2.62$), and the IJA condition, ($t(20.08) = 3.24$, $p = .004$, $d = 1.45$) were found suggesting that the ASD group may have spent more time looking off-screen, or the eye tracker detected fewer of their gaze samples. Wass, Forssman and Leppanen (2014), recently compared eye tracking data quality from infants and young children with and without ASD. They cautioned that the quality of gaze data can increase with age and decrease with increased movement and 'fidgetiness'. It may be possible that the ASD participants in the current study were more fidgety than the TD participants, although this was not recorded. To the author's knowledge, no study to date has compared the quality of gaze data collected from school-aged children with and without ASD.

Individual group analysis using paired samples *t*-tests found no significant differences in on-screen time between the RJA and IJA conditions for the ASD group ($t(20) = -.066$, $p = .948$). A small but statistically significant difference was found for the TD group, with 1.47% less on-screen time in the IJA condition than the RJA condition ($t(23) = -19.65$, $p < .001$, $d = 4.01$).

AOI analysis, experiment 2.1

Inspection of the gaze data when broken down for image type revealed two outliers from the ASD group, one demonstrated increased viewing of abstract non-target images and the other increased viewing outwith the main AOIs in the face images condition. These scores were replaced with the group mean plus two times the standard deviation. Two (group, ASD/TD) × 2 (JA condition, RJA/IJA) × 3 (Image type, abstract/face/house) mixed ANOVAs were conducted on the gaze data for each AOI separately. Table 3.13 shows average total viewing times for each AOI.

Target images

Data from the TD group for the RJA abstract target images demonstrated slight negative skew, transformations of the data incurred more skew so the original data were used for analysis. Analysis of viewing times to target images suggested a significant main effect of JA condition ($F(1,43) = 114.89$, $p < .001$, $\eta_p^2 = .73$) with longer target viewing times in the RJA condition than the IJA condition. There was also a significant main effect of group ($F(1, 43) = 19.62$, $p < .001$, $\eta_p^2 = .31$) suggesting longer target viewing times for the TD group than the ASD group. A significant interaction between image type and group was found ($F(2,86) = 5.01$, $p = .009$, $\eta_p^2 = .10$). No other significant main effects or interactions were found (all $F \leq 2.54$, $p \geq .085$, $\eta_p^2 \leq .10$).

To further investigate the interaction between image type and group, two separate repeated measures ANOVAs were conducted for the ASD group and TD group.

ASD group

The ANOVA for the ASD group suggested a significant main effect of JA condition ($F(1,20) = 72.56$, $p < .001$, $\eta_p^2 = .78$) where target viewing times were greater in the RJA condition than the IJA condition. No significant main effect of image type ($F(2,40) = .794$, $p = .46$) or interaction between JA condition and image type was found ($F(1,40) = 2.82$, $p = .115$).

TD group

The ANOVA for the TD groups' data suggested a significant main effect of JA condition ($F(1,23) = 49.82$, $p < .001$, $\eta_p^2 = .68$) and image type ($F(2,46) = 5.43$, $p = .008$, $\eta_p^2 = .19$). Bonferroni corrected pairwise comparisons suggested significantly lower viewing times for target face images than target house images ($p = .004$). The difference in viewing times between face and abstract target images approached but did not reach significance ($p = .060$) there was also no significant difference between abstract and house target viewing times ($p = 1.00$). No interaction between JA condition and image type was found ($F(2,46) = .561$, $p = .575$, $\eta_p^2 = .02$).

Overall analysis of target viewing times suggests that both groups spent more time viewing the target images in the RJA condition. Overall, the TD group spent less time looking at face target images than house target images. The target image type did not affect viewing times for the ASD group.

Non-target images

Shapiro-Wilks tests suggested the data for the non-target images were non-normal and demonstrated positive skew. Square root transformations of the data eliminated the skew but Shapiro-Wilks tests suggested that some data from the TD group remained non-normal. The original data were therefore used for the reported analysis.

The ANOVA suggested a significant main effect of group (F(1,43) = 5.80, p = .020, η_p^2 = .12), JA condition (F(1,43) = 43.45, p < .001, η_p^2 = .50) and image type (F(2,86) = 3.64, p = .031, η_p^2 = .08). There was also a significant two-way interaction between image type and group (F(2,86) = 5.43, p = .006, η_p^2 = .11) and a significant three-way interaction between JA condition, image type and group (F(2,86) = 4.21, p = .018, η_p^2 = .09). No other interactions reached significance (all $F \leq$ .1.55, $p \geq$ .291, $\eta_p^2 \leq$ .04).

To further investigate the significant three-way interaction between JA condition, image type and group, two 2 (JA condition, RJA/IJA) × 3 (Image type, abstract/face/house) ANOVAs were conducted for the ASD and TD groups separately.

ASD group

The ANOVA for the ASD group suggested no significant main effect of image type (F(2,40) = .059, p = .943) and a significant main effect of JA condition (F(1,20) = 21.87, p < .001, η_p^2 = .52), where non-target viewing times were higher in the IJA condition. There was also a significant interaction between JA condition and image type (F(2,40) = 3.97, p = .027, η_p^2 = .17). To further investigate this two-way interaction, repeated measures ANOVAs were conducted for the RJA and IJA conditions separately, and revealed no significant main effect of image type for either the RJA (F(2,40) = 1.43, p = .252) or IJA (F(2,40) = 1.30, p = .284) conditions.

TD group

The ANOVA for the TD groups' non-target image viewing times suggested a significant main effect of JA condition (F(1,23) = 21.50, p < .001, η_p^2 = .48) with increased viewing times in the IJA condition. There was also a significant main effect of image type (F(2,46) = 15.57, p < .001, η_p^2 = .40) and no significant interaction between JA condition and image type (F(2,46) = .895, p = .415). Bonferroni corrected pairwise comparisons suggested that TD participants viewed non-target face images for longer than non-target abstract (p = .001) and house images (p < .001). No difference in viewing times for non-target abstract and house images was found (p = 1.00).

Overall, analysis of non-target viewing times suggested that both groups spent more time viewing non-target images in the IJA condition. For the TD group, non-target face images seemed to cause greater distraction with higher viewing times than non-target abstract or house images. Again, there appeared to be no effect of image type for the ASD group.

The avatar

The gaze data for the avatar AOI were positively skewed. Levene's test also indicated unequal variance for face (F(1,43) = 11.01, p = .002) and house images (F(1,43) = 22.77, p < .001) in the RJA condition and for house images in the IJA condition (F(1,43) = 8.53, p = .006). Square root transformations eliminated the skew but Shapiro-Wilk tests suggested that the data remained non-normal in two conditions for the TD group. However, Levene's test suggested that the square root transformations led to equal variance for all conditions. The transformed data were therefore used for analysis.

The ANOVA on the transformed data revealed a significant main effect of group (F(1,43) = 21.64, p <.001, η_p^2 = .34) with longer avatar viewing times from the ASD group (M = 6170, SD = 3247) than the TD group (M = 3076, SD = 1622). There was also a significant main effect of JA condition (F(1,43) = 123.42, p < .001, η_p^2 = .74) suggesting significantly longer avatar viewing times in the IJA condition (M = 3334, SD = 2133) than the RJA condition (M = 1170, SD = 1132). No other significant main effects or interactions were found (all $F \leq 3.74$, $p \geq .060$, $\eta_p^2 \leq .08$).

Overall, the results of this analysis suggest significantly more looking time at the avatar in the IJA condition for both of the groups. Overall, the ASD group looked more at the avatar than the TD group during the task show target period.

Viewing times and recognition memory, experiment 2.1.

To investigate the relationship between target and non-target viewing times and *d'* scores, correlation analyses were conducted. When ASD and TD groups were considered together, *d'* scores and target viewing times were significantly positively correlated for the RJA (r(47) = .588, p < .001) and IJA (r(47) = .580, p < .001) conditions overall. This suggests that increased target image viewing was associated with better memory task responses. *d'* scores and non-target viewing times were significantly negatively correlated for the RJA (r(47) = -.409, p = .004) and IJA (r(47) = -.380, p = .008) conditions overall, suggesting that increased non-target image viewing was associated with poorer memory task performance.

Table 3.13.

Total viewing times, experiment 2.1

		ASD				TD			
JA cond.	AOI	Overall	Abstract	Face	House	Overall	Abstract	Face	House
RJA	Target	16032 (3562)	5392 (1140)	5299 (1244)	5341 (1454)	20040 (2799)	6670 (1141)	6509 (1128)	6861 (862)
	Non-target	2743 (1968)	936 (560)	972 (782)	771 (676)	1413 (1414)	367 (501)	663 (612)	383 (487)
	Avatar	1935 (1190)	645 (443)	640 (550)	650 (542)	500 (465)	265 (332)	123 (141)	113 (164)
IJA	Target	11330 (3395)	3648 (1048)	4013 (1286)	3669 (1285)	15427 (3750)	5246 (1286)	4859 (1318)	5323 (1380)
	Non-target	4986 (2612)	1644 (937)	1534 (1049)	1808 (955)	3494 (2779)	1006 (883)	1460 (957)	1028 (1083)
	Avatar	4201 (2487)	1350 (908)	1373 (833)	1478 (1070)	2576 (1428)	892 (650)	817 (502)	867 (591)

Experiment 2.2 memory test results

Experiment 2.2 aimed to investigate the effect of the avatar's response to the participant's IJA on their recognition memory for the target. Here participants' responses when their gaze initiation was followed (gaze-followed condition) and ignored (gaze-ignored condition) were compared. The mixed block design where gaze-followed and gaze-ignored trials were presented in the same block meant *d'* could not be calculated for experiment 2.2. The dependent variable was therefore the percentage of correct "yes" responses for target images. The percentage of non-target images responded to with a "yes" response was also calculated. Two participants from the ASD group declined to take part in the final task, 1 participant with ASD had moved schools so was unable to complete the final task and 3 ASD participants and 1 TD participant were unable to take part due to problems with eye tracker calibration (total participants who completed experiment 2.2: ASD N= 24, TD N= 32).

Only 10 participants with ASD performed at above chance level (>50% target hit accuracy) for both the gaze-followed and gaze-ignored conditions. Their mean age at the time of experiment 2.2 was 128.60 months (SD = 21.50) and all participants had a FSIQ of ≥70 (M = 89.5, SD = 13.18). Nineteen participants from the TD group performed at above chance level for both the gaze followed and gaze ignored conditions. All TD participants had a FSIQ of ≥70 (M = 89.19, SD =10.87) and their mean age at the time of experiment 2.2 was 124.15 months (SD = 16.58). To compare the groups, ASD participants who scored above chance level were compared with their TD matches. Where a TD match was removed from the analysis due to chance performance they were replaced with their best remaining match. This led to 7 ASD participants being matched with their closest remaining match. Independent samples t-tests suggested no significant differences in age ($t(18) = .158$, $p = .876$) or IQ ($t(18) = .377$, $p = .942$) between the groups and significantly different SCQ scores ($t(15) = 6.70$, $p < .001$, $d = 3.46$). No differences in total scores ($t(18) = .404$, $p = .691$) or memory span ($t(18) = .00$, $p = 1.00$) for the Corsi blocks task was found between the groups. Table 3.14 shows participants' mean age, IQ and SCQ and Corsi block score and the ASD group ADOS score.

Table 3.14.

Participant characteristics, experiement 2.2

	ASD (N = 10)	TD (N = 10)
Age in months	128.60 (21.50)	127.30 (14.51)
FSIQ-4	89.50 (13.17)	89.90 (10.87)
SCQ score	22.00 (6.63)*** [a]	4.13 (3.80)*** [b]
ADOS total score	11.10 (3.5)	N/A
Corsi total score	37.5 (25.01)	33.90 (12.89)
Corsi memory span	4.40 (1.20)	4.40 (0.88)

*** $p < .001$
[a] 9 SCQ questionnaires returned
[b] 8 SCQ questionnaires returned.

Table 3.15 shows the mean percentage of "yes" responses to both target and non-target images in the memory task for both groups.

Table 3.15.

ASD & TD group mean percentage of 'yes' responses for target and non-target images, experiment 2.2

JA condition	Image cat	Image type	ASD (N=10)	TD (N=10)
Gaze followed	Target	Overall	68.33 (13.63)	71.25 (9.51)
		Abstract	75.77 (18.07)	82.50 (10.54)
		Face	62.45 (27.83)	61.25 (27.83)
		House	63.44 (17.79)	70.00 (19.72)
Gaze ignored	Target	Overall	61.67 (9.98)	74.17 (13.72)
		Abstract	67.19 (18.33)	78.75 (15.64)
		Face	57.82 (20.93)	68.75 (13.50)
		House	60.47 (17.11)	75.00 (24.30)
Gaze followed	Non-target	Overall	55.00 (17.98)	21.25 (25.64)
		Abstract	58.87 (24.02)	23.75 (31.98)
		Face	46.25 (31.49)	23.75 (29.73)
		House	56.41 (13.73)	16.25 (19.58)
Gaze ignored	Non-target	Overall	47.92 (15.50)	20.00 (15.93)
		Abstract	53.87 (21.03)	18.75 (18.87)
		Face	39.38 (25.54)	26.25 (20.79)
		House	49.48 (17.29)	15.00 (17.48)

Effect of JA, experiment 2.2.

A 2 (JA condition, RJA/IJA) × 2 (group, ASD/TD) mixed ANOVA on the % accuracy scores, with 'group' as the between-groups factor revealed no significant main effect of JA condition ($F(1,18) = .526$, $p = .477$) or group ($F(1,18) = 2.76$, $p = .114$) and no interaction between JA condition and group $F(1,18) = 3.44$, $p = .080$).

Effect of image type, experiment 2.2

Shapiro-Wilk tests suggested the data from some conditions were not normally distributed. This was not improved with transformations of the data. Levenes test also indicated unequal variance for abstract ($F(1,18) = 4.79$, $p = .042$) and face image ($F(1,18) = 10.09$, $p = .005$) in the gaze followed condition. Due to the mixed design, equal groups and robustness of analysis of variance a 2 (group, ASD/TD) × 2 (JA condition: gaze followed, ignored) x 3 (image type, abstract/face/house) mixed ANOVA with 'group' as the between-groups factor was conducted on the original target image accuracy data. This revealed no significant main effect of group ($F(1,18) = 3.15$, $p = .093$) or JA condition ($F(1,18) = .236$, $p = .633$). There was a significant main effect of image type ($F(2,36)=6.29$, $p =.005$ $\eta_p^2 = .26$). Bonferroni corrected pairwise comparisons suggested no significant differences in accuracy between abstract and house images ($p = .092$) and between the house and face images ($p = .787$). However, accuracy for face images was significantly lower than for the abstract images ($p = .007$). No interactions were significant (all $F \leq .532$, $p \geq .592$, $\eta_p^2 \leq .03$).

Non-target images

Data for non-target images were positively skewed, transformations did not improve the normality of the data so the original data were used for analysis. To investigate participants' responses to non-target images, and whether this differed from target images and between the groups, a 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 2 (image category, target/non-target) × 3 (image type, abstract/face/house) mixed ANOVA with group as the between-groups factor, was conducted on the percentage of target hits and the percentage of non-target images participants reported to remember. This revealed no significant main effect of JA condition (F(1,18) = 1.89, p = .186). Significant main effects of group (F(1,18) = 5.43, p = .032 η_p^2 = .23), image category (F(1,18) = 52.04, p < .001 η_p^2 = .74) and image type (F(2,36) = 4.04, p = .026 η_p^2 = .18) were found. There was also a significant interaction between image category and group (F(1,18) = 17.57, p = .001, η_p^2 = .49) and a significant three way interaction between image category, image type and group (F(2,36) = 5.56, p = .008, η_p^2 = .24). No other interactions reached significance (all $F \leq 3.57$, $p \geq .084$, $\eta_p^2 \leq .16$).

To further investigate this three way interaction between image category, image type and group a separate 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 3 (image type, abstract/face/house) mixed ANOVA with group as the between-groups factor, was conducted on the non-target image responses (see above target hits analysis for group differences for target responses). This revealed a significant main effect of group (F(1,18) = 14.05, p = .001 η_p^2 = .44) with the ASD group reporting significantly higher "yes" responses for non-target images than the TD group. No main effect of JA condition (F(1,18) =1.45, p = .244) or image type (F(2,36) = 0.94, p = .399) was found. Similarly, interactions between JA condition and group (F(1,18) = .646, p =.432) and JA condition and image type (F(2,36) = .101, p = .904) were not significant. There was a significant interaction between image type and group (F(2,36) = 3.62, p =.037 η_p^2 = .17). This interaction is plotted in figure 3.4. Bonferroni corrected pairwise comparisons suggest no significant differences between the groups for 'yes' responses to face non-target images (p =

.109) but a significantly lower percentage of 'yes' responses in the TD group than the ASD group for abstract (p = .002) and house non-target images (p <.001). Furthermore no significant differences between non-target hits for the image types were significant for either group (all p > .05)

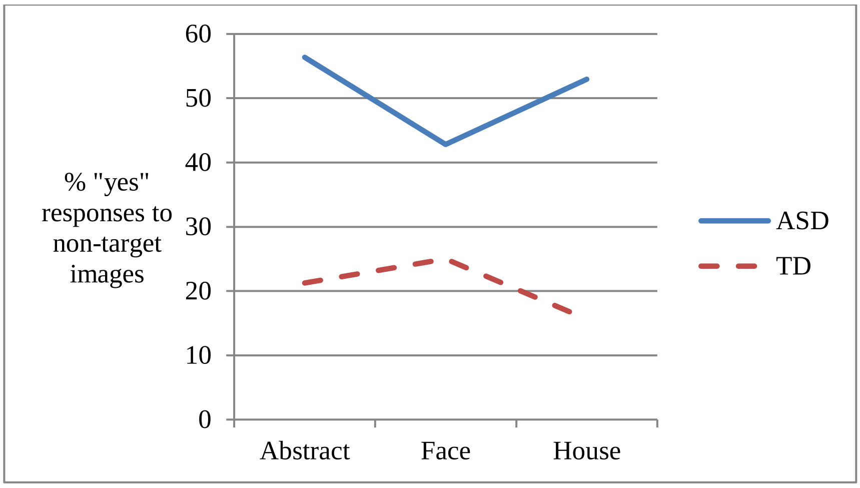

Figure 3.4. Non-target images remembered, ASD & TD group, experiment 2.2

Gaze data analysis, experiment 2.2.

As in experiment 2.1, on-screen percentage viewing time and total viewing times for the AOIs were calculated for experiment 2.2. The gaze data were also visually inspected for anomalies. Mean 'on-screen' percentages for each group are shown in table 3.16 and mean total viewing times (ms) to the AOIs for the show-target period are presented in table 3.17.

Table 3.16.

Percentage 'On-screen' performance, experiment 2.2

Group	On-task % gaze followed	On-task % gaze ignored
ASD (N=10)	93.74 (5.01)	92.56 (9.13)
TD (N=10)	93.85 (6.74)	95.59 (4.29)

Percentage on screen performance, experiment 2.2

The on-screen percentage data showed evidence of negative skew. A square-root transformation completely eliminated this skew so the transformed data were used for analysis. Independent samples t-tests were conducted to compare on screen percentage viewing time between the groups. No significant differences in on-screen percentage between the ASD and TD groups for gaze followed ($t(18) = .500$, $p = .623$) and gaze ignored conditions ($t(18) = .791$, $p = .439$) were found. Individual group analysis using paired samples t-tests also found no significant differences in on-screen viewing time between the gaze followed and ignored conditions for the ASD group ($t(9) = -.921$, $p = .381$) and the TD group ($t(9) = -6.10$, $p = .557$).

AOI analysis, experiment 2.2.

To investigate the effect of JA condition, separate 2 (Group, ASD/TD) × 2 (JA condition, gaze followed/ignored) ANOVAs were conducted for total viewing times for each AOI.

Table 3.17.

AOI total viewing times, experiment 2.2

JA cond.	AOI	ASD group N = 10	TD group N = 10
Gaze followed	Target	12624 (3525)	18648 (5451)
	Non-target	4396 (2635)	2285 (3046)
	Avatar	3524 (2814)	778 (1212)
Gaze ignored	Target	7321 (4235)	18443 (5162)
	Non-target	8169 (4454)	2084 (2688)
	Avatar	4304 (3230)	1046 (1556)

Target Images

The ANOVA for target image viewing times revealed a significant main effect of group ($F(1,18) = 20.29$, $p < .001$, $\eta_p^2 = .53$), JA condition ($F(1,18) = 10.63$, $p = .004$, $\eta_p^2 = .37$) and a significant interaction between JA condition and group ($F(1,18) = 9.10$, $p = .007$, $\eta_p^2 = .34$). Bonferroni corrected pairwise comparisons suggested significantly greater target viewing times for the TD group compared to the ASD group in the gaze followed ($p = .009$) and ignored ($p < .001$) conditions. Significantly lower viewing times to target images in the gaze-ignored condition than gaze-followed condition were also found for the ASD group ($p < .001$). No significant difference in target viewing times was found for the TD group ($p = .865$).

Non-target images

The ANOVA for non-target image viewing times revealed a significant main effect of group ($F(1,18) = 10.64$, $p = .004$, $\eta_p^2 = .37$) and JA condition ($F(1,18) = 5.45$, $p = .031$, $\eta_p^2 = .23$) and a significant interaction between JA condition and group ($F(1,18) = 6.74$, $p = .018$, $\eta_p^2 = .27$). Bonferroni corrected pairwise comparisons suggested no group differences in non-target viewing times for the gaze followed condition ($p = .115$) but significantly higher non-target viewing time in the gaze ignored condition for the ASD group ($p = .002$). For the TD group viewing times to non-target images was not significantly different between the JA conditions ($p = .855$) but the ASD group spent more time viewing non-target images in the gaze ignored condition than the gaze-followed condition ($p = .003$).

Avatar

TD participants' viewing time data for the avatar were positively skewed, and transformations did not eliminate this skew so the original data were used for the analysis. The ANOVA for viewing times to the avatar revealed a significant main effect of group ($F(1,18) = 8.39$, $p = .010$, $\eta_p^2 = .32$) with the ASD group looking for longer at the avatar than the TD group. A significant main effect of JA condition ($F(1,18) = 7.21$, $p = .015$, $\eta_p^2 = .29$) was also found where participants looked at the avatar more in the gaze ignored condition. No significant interaction between JA condition and group was found ($F(1,18) = 1.73$, $p = .205$).

Effect of image type

Due to the uneven presentation of image types in the gaze followed and ignored conditions for 22 ASD participants, viewing times for each individual image type AOI were calculated as a proportion of total viewing time for the specific image type. Mean proportion viewing times and standard deviations can be found in table 3.18. To investigate the effect of image type and joint attention condition on AOI viewing times, separate 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 3 (Image type, abstract/face/house) mixed ANOVAs were conducted for the AOIs.

Target images

Target viewing time data for both groups demonstrated negative skew. Transformations eliminated this skew for the TD group, but incurred more skew for the ASD group. The original data were therefore used for analysis.

The ANOVA revealed a significant main effect of JA condition ($F(1,18) = 8.83$, $p = .008$, $\eta_p^2 = .37$) and group ($F(1,18) = 26.02$, $p < .001$, $\eta_p^2 = .59$). There was also a significant interaction between JA condition and group ($F(1,18) = 8.51$, $p = .009$, $\eta_p^2 = .32$). No other main effects or interactions reached significance (all $F \leq 1.61$, $p \geq .215$, $\eta_p^2 \leq .082$). Bonferroni corrected pairwise comparisons suggested significantly less target viewing by the ASD group than the TD group in the gaze followed ($p = .008$) and gaze ignored ($p < .001$) conditions. Furthermore, no significant differences in target viewing times between the gaze followed and ignored condition were found for the TD group ($p = .969$). The ASD group looked significantly longer at the target images when their gaze was followed rather than ignored ($p = .001$).

Non-target images

Viewing time data for the non-target images were positively skewed for the TD group. Transformations did not eliminate the skew so the original data were used for analysis. The ANOVA suggested a significant main effect of JA condition ($F(1,18) = 6.22$, $p = .023$, $\eta_p^2 = .26$) and group ($F(1,18) = 11.35$, $p = .005$, $\eta_p^2 = .39$) and no main effect of image type ($F(2,36) = .182$, $p = .834$, $\eta_p^2 = .01$). There was a significant interaction between JA condition and group ($F(1,18) = 7.66$, $p = .013$, $\eta_p^2 = .30$). Bonferroni corrected pairwise comparisons suggested no significant differences in non-target viewing between the ASD and TD groups in the gaze followed condition ($p = .134$). In the gaze-ignored condition, the ASD group looked significantly more at non-targets than the TD group ($p = .001$). Pairwise comparisons also suggested that the ASD group looked significantly more at non-target images in the gaze-ignored condition than the gaze-followed condition ($p = .002$). No such difference between JA conditions was found for the TD group ($p = .848$). A significant interaction between JA condition and image type $F(2,36) = 5.78$, $p = .007$, $\eta_p^2 = .24$) was also found. Bonferroni corrected pairwise comparisons suggested significantly more non-target viewing in the gaze-ignored condition than the gaze-followed condition for abstract ($p = .048$) and face ($p = .004$) images. Comparisons of all of the image types were non-significant in the gaze-followed condition (all $p \geq .446$) and the gaze ignored condition (all $p \geq .1$).

Avatar

Viewing time data to the avatar were positively skewed, transformations did not remove this skew so the original data were used for analysis. The ANOVA revealed a significant main effect of group ($F(1,18) = 6.75$, $p = .018$, $\eta_p^2 = .27$), where the ASD group looked at the avatar for longer than the TD group. There was also a significant main effect of JA condition ($F(1,18) = 4.84$, $p = .041$, $\eta_p^2 = .21$), where participants looked at the avatar significantly more in the gaze ignored condition. No other main effects or interactions were significant (all $F \leq 1.40$, $p \geq .097$, $\eta_p^2 \leq .12$).

Table 3.18.

AOI proportion viewing times per image type, experiment 2.2

		ASD group			TD group		
JA cond.	AOI	Abstract	Face	House	Abstract	Face	House
Gaze followed	Target	60.71 (14.73)	59.13 (17.32)	61.99 (19.78)	83.71 (23.65)	87.62 (16.80)	82.33 (21.51)
	Non-target	20.39 (13.27)	20.09 (14.51)	21.55 (9.99)	12.33 (17.46)	8.61 (14.07)	12.92 (15.73)
	Avatar	18.90 (14.66)	20.77 (23.28)	16.47 (20.31)	3.96 (7.98)	3.77 (6.56)	4.75 (7.79)
Gaze ignored	Target	37.31 (21.69)	34.74 (19.48)	37.49 (14.41)	84.31 (20.02)	82.02 (16.95)	86.65 (23.07)
	Non-target	40.70 (20.24)	43.47 (20.24)	37.52 (21.04)	9.38 (14.61)	12.65 (13.63)	8.71 (14.69)
	Avatar	21.99 (14.02)	21.78 (21.17)	24.99 (22.36)	6.31 (10.49)	5.32 (7.74)	4.64 (8.94)

Viewing times and recognition memory, experiment 2.2.

To investigate the relationship between target and non-target viewing times and the percentage of accurate target hits and "yes" responses for non-target images, correlation analyses were conducted. When ASD and TD groups were considered together, target percentage accuracy and target viewing times were not significantly correlated for the gaze-followed ($r(20) = .004$, $p = .986$) or gaze-ignored ($r(20) = .431$, $p = .058$) conditions. Target percentage accuracy and non-target viewing times were significantly negatively correlated for the gaze ignored condition ($r(20) = -.462$, $p < .040$) and not significantly correlated for the gaze-followed condition ($r(20) = -.426$, $p = .061$). This suggests that for the gaze-ignored condition increased non-target image viewing was associated with poorer target image recognition.

The number of hits for non-target images was significantly positively correlated with non-target viewing times for the gaze-followed ($r(20) = .477$, $p = .039$) and gaze-ignored ($r(20) = .552$, $p = .012$) conditions, suggesting that more non-target viewing was associated with greater "yes" responses for non-target images. The number of hits for non-target images and target viewing times was significantly negatively correlated for the gaze-followed ($r(20) = -.906$, $p < .001$) and gaze-ignored ($r(20) = -.835$, $p < .001$) conditions, suggesting that increased target viewing time was associated with reduced "yes" responses for non-target images.

All participants with ASD & their matches

To investigate the performance of all of the participants with ASD who completed the task, a further analysis was conducted with all of the ASD participants and their TD matches (N = 24 for each group). One participant with ASD was matched with their next closest match because their TD match did not complete the task.

Independent samples t-tests suggested no significant differences between the groups in IQ ($t(46) = -.136$, $p = .892$), age at the time of experiment 2.2 ($t(46) = .496$, *p* = .622), Corsi blocks task total score (*t*(46) = -.182, *p* = .856) or memory span (*t*(46) = -.718, *p* = .476). Where SCQ scores were available, these were significantly different between the groups (*t*(34) = 9.44, *p* < .001, *d* = 3.24). Table 3.19 shows participants mean age, IQ, SCQ, ADOS and Corsi block scores for both groups

Table 3.19,

Participant characteristics of all participants completing study 2, experiment 2.2

	ASD (N=24)	TD (N=24)
FSIQ-4	89.25 (13.68)	89.75 (11.62)
Age in months	127.54 (22.34)	124.71 (16.87)
SCQ score	24.22 (6.83)***[a]	5.94 (4.56)***[b]
ADOS total score	10.5 (3.11)	N/A
Corsi total score	31.46 (20.30)	32.33 (11.97)
Corsi memory span	4.04 (1.17)	4.25 (0.81)

*** *p* <.001
[a]17 SCQ questionnaires returned
[b]20 SCQ questionnaires returned

Table 3.20 shows the mean percentage of “yes” responses to both target and non-target images in the memory task for both groups.

Table 3.20

ASD & TD group mean percentage of 'yes' responses for target and non-target images, all participants who completed experiment 2.2

JA condition	Image cat	Image type	ASD (N=24)	TD (N=24)
Gaze followed	Target	Overall	57.81 (16.77)	62.84 (14.16)
		Abstract	67.19 (18.57)	71.35 (18.61)
		Face	50.31 (26.63)	57.29 (21.15)
		House	55.43 (27.83)	59.90 (19.84)
Gaze ignored	Target	Overall	44.97 (20.89)	55.90 (21.17)
		Abstract	48.75 (27.94)	57.81 (29.21)
		Face	41.36 (27.45)	54.69 (22.96)
		House	43.56 (23.30)	55.21 (22.40)
Gaze followed	Non-target	Overall	39.23 (21.03)	31.42 (22.15)
		Abstract	40.04 (27.12)	32.81 (27.04)
		Face	36.88 (27.45)	30.21 (24.70)
		House	38.58 (21.40)	31.25 (26.83)
Gaze ignored	Non-target	Overall	48.78 (15.76)	36.28 (22.67)
		Abstract	53.55 (18.91)	42.19 (31.88)
		Face	43.24 (23.05)	36.46 (20.16)
		House	50.50 (23.49)	30.21 (27.07)

Effect of JA, experiment 2.2.

A 2 (JA condition, RJA/IJA) × 2 (group, ASD/TD) mixed ANOVA on the % accuracy scores, with 'group' as the between-groups factor revealed a significant main effect of JA condition ($F(1,46) = 11.46$, $p < .001$, $\eta_p^2 = .20$), with greater overall percentage accuracy for the gaze followed condition (M = 60.33 SD = 15.57) than the gaze ignored condition (M = 50.43, SD = 21.52). There was no significant main effect of group ($F(1,46) = 3.20$, $p = .080$) and no interaction between JA condition and group $F(1,46) = 1.02$, $p = .318$).

Effect of Image type, experiment 2.2.

To investigate any effect of image type, a 2 (group, ASD/TD) × 2 (JA condition: gaze followed, ignored) x 3 (image type, abstract/face/house) mixed ANOVA with 'group' as the between-groups factor was conducted. This again revealed no significant main effect of group ($F(1,46)= 3.42$, $p = .071$). There was a significant main effect of JA condition ($F(1,46)= 12.47$, $p = .001$, $\eta_p^2 = .21$) and a significant main effect of image type ($F(2, 92) = 6.37$, $p = .003$, $\eta_p^2 = .12$). Bonferroni corrected pairwise comparisons suggested no significant differences in accuracy between face and house images ($p = 1.00$), or house and abstract images ($p = .057$). Accuracy for face images was significantly lower than accuracy for abstract images ($p = .002$). No interactions were significant (all $F \leq 2.31$, $p \geq .105$, $\eta_p^2 \leq .05$).

Non-target images

To investigate participants' responses to non-target images, and whether this differed from target images and between the groups, a 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 2 (image category, target/non-target) mixed ANOVA with group as the between-groups factor, was conducted on the percentage of target hits and the percentage of non-target images participants reported to remember. This revealed no significant main effect of JA condition (F(1,46) = 1.05, p = .312) or group (F(1,46) = .09, p = .770). There was a significant main effect of image category (F(1,46) = 28.75, p < .001, η_p^2 = .38), with a higher percentage of "yes" responses to target images (M = 55.57, SD = 14.99) than non target images (M = 37.74, SD = 17.82) overall. There was also a significant interaction between image category and group (F(1,46) = 8.75, p = .005, η_p^2 = .16). Bonferroni corrected pairwise comparisons suggested no significant differences between the groups in their overall responses to target images (p = .080) and non-target images (p = .053). The TD group responded with significantly more "yes" responses to target images (M = 61.19, SD = 13.37) than non-target images (M = 31.98, SD = 20.31) overall (p < .001). However, for the ASD group, responses to target images (M = 49.82, SD = 14.14) and non-target images (M = 42.75, SD = 13.92) were not significantly different (p = .096).

The ANOVA also suggested a significant interaction between image category and JA condition (F(1,46) = 10.25, p = .002, η_p^2 =.18), Bonferroni corrected pairwise comparisons suggested a higher percentage of "yes" responses for target images (M = 60.33, SD = 15.57) than non-target images (M = 35.33, SD = 21.75) in the gaze followed condition (p < .001), however the difference between overall responses to target (M = 50.43, SD = 21.53) and non-target (M = 42.53, SD = 20.32) images was not significant for the gaze ignored condition (p = .094). Furthermore the percentage of targets remembered was significantly higher in the gaze-followed condition than the gaze ignored condition (p = .001) and the number of non-target hits was significantly greater in the gaze-ignored condition than the gaze followed condition

(p = .022). No other interactions reached significance (all $F \leq 1.05$, $p \geq .312$, $\eta_p^2 \leq$ .02).

Effect of Image type

To investigate the effect of image type and non-target images, and whether this differed from target images and between the groups, a 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 2 (image category, target/non-target) × 3 (image type, abstract/face/house) mixed ANOVA with group as the between-groups factor, was conducted on the percentage of target hits and the percentage of non-target images participants reported to remember. This revealed no significant main effect of JA condition ($F(1,46) = .786$, $p = .380$) or group ($F(1,46) = .052$, $p = .821$). There was a significant main effect of image category ($F(1,46) = 28.45$, $p < .001$, $\eta_p^2 = .38$) and image type ($F(2,92) = 5.91$, $p = .004$, $\eta_p^2 = .11$). There was also a significant interaction between image category and group ($F(1,46) = 8.76$, $p = .005$, $\eta_p^2 = .16$), image category and JA condition ($F(1,46) = 11.30$, $p = .002$, $\eta_p^2 = .20$) and a significant three way interaction between image category, JA condition and image type ($F(2,92) = 3.19$, $p = .046$, $\eta_p^2 = .07$). No other interactions reached significance (all $F \leq 1.06$, $p \geq .266$, $\eta_p^2 \leq .01$).

To further investigate the significant three-way interaction, separate 2 (JA condition, gaze followed/gaze ignored) x 3 (Image type, abstract/face/house) ANOVAs were conducted on the target image responses and non-target image responses separately.

Target images

This revealed a significant main effect of JA condition (F(1,47) = 12.42, p < .001, η_p^2 = .21) with a higher percentage accuracy in the gaze followed condition than the gaze ignored condition. There was also a significant main effect of image type F(2,94) = 6.48, p = .002, η_p^2 = .12) with Bonferroni corrected pairwise comparisons suggesting significantly greater accuracy for abstract images than face images (p = .002). No significant interaction between JA condition and image type was found F(2,94) = 2.35, p = .101).

Non-target images

The ANOVA on responses to non-target images revealed a significant main effect of JA condition (F(1,47) = 6.49, p = .014, η_p^2 = .12) with a higher percentage of "yes" responses in the gaze ignored condition than the gaze followed condition. No significant main effect of image type F(2,94) = 2.03, p = .138) and no significant interaction between JA condition and image type was found F(2,94) = 1.09, p = .340).

Gaze data analysis, experiment 2.2

The gaze data were visually inspected for anomalies; one participant from the TD group and two participants from the ASD group were removed from the gaze data analysis due to eye tracker error leading to missing trials. One further participant from the ASD group was removed from the analysis due to outlier responses (z-score >3.29). Mean 'on-screen' percentages for each group are shown in table 3.21 and mean total viewing times (ms) to the AOIs for the show-target period are presented in table 3.22.

Table 3.21.

Percentage 'On-screen' performance, all participants who completed experiment 2.2

Group	On-task % gaze followed	On-task % gaze ignored
ASD (N=21)	94.92 (4.79)	93.18 (7.90)
TD (N=23)	95.66 (5.48)	95.70 (6.06)

Percentage on screen performance, experiment 2.2

The on-screen percentage data showed evidence of negative skew. Transformations did not reduce this skew for either group so the original data were used for analysis. Independent samples t-tests were conducted to compare on screen percentage viewing time between the groups. No significant differences were found for on-screen percentage between the ASD and TD groups for the gaze followed ($t(42) = -.477$, $p = .636$) or gaze ignored ($t(42) = -1.19$, $p = .240$) conditions.

Individual group analysis using paired samples t-tests also found no significant differences in on-screen viewing time between the gaze followed and ignored conditions for the ASD group ($t(20) = 1.69$, $p = .106$) and the TD group ($t(22) = -.046$, $p = .964$).

AOI analysis, experiment 2.2.

To investigate the effect of JA condition, separate 2 (Group, ASD/TD) × 2 (JA condition, gaze followed/ignored) ANOVAs were conducted for total viewing times for each AOI.

Table 3.22.

AOI total viewing times, all participants who completed experiment 2.2

JA cond.	AOI	ASD group N = 21	TD group N = 23
Gaze followed	Target	13215 (3353)	16746 (5418)
	Non-target	4718 (2339)	3959 (3278)
	Avatar	2906 (1936)	1359 (1196)
Gaze ignored	Target	8814 (5244)	13893 (6975)
	Non-target	8235 (4264)	6162 (5460)
	Avatar	3510 (2510)	1778 (1717)

Target Images

The ANOVA for target image viewing times revealed a significant main effect of group ($F(1,42) = 9.11$, $p = .004$, $\eta_p{}^2 = .18$), with higher target viewing times for the TD group (M = 15340, SD = 5548) than the ASD group (M = 11014 , SD = 3616). There was also a significant main effect of JA condition ($F(1,42) = 19.77$, $p < .001$, $\eta_p{}^2 = .32$), with greater target viewing times in the gaze-followed condition (M = 15061, SD = 4840) than the gaze ignored condition (M = 11469, SD = 6654). No significant interaction was found between JA condition and group ($F(1,42) = .902$, $p = .348$).

Non-target images

The data for the non-target images demonstrated signs of positive skew for the TD group. A square root transformation eliminated this skew, so the transformed data were used for analysis. The ANOVA for non-target image viewing times revealed a significant main effect of JA condition (F(1,42) = 11.56, p < .001, η_p^2 = .09) with greater non-target viewing in the gaze ignored condition (M = 7151, SD = 4980) than the gaze followed condition (M = 4322, SD = 2862). No significant main effect of group (F(1,42) = 3.77, p = .050, η_p^2 = .08) and no significant interaction between JA condition and group was found (F(1,42) = .479, p = .493).

Avatar

TD participants' viewing time data for the avatar were positively skewed. Square root transformations eliminated this skew so the transformed data were used for the analysis. The ANOVA for viewing times to the avatar revealed a significant main effect of group (F(1,42) = 10.26, p = .003, η_p^2 = .20) with the ASD group looking for longer at the avatar (M = 6417, SD = 4264) than the TD group (M = 3137, SD = 2793). A significant main effect of JA condition (F(1,42) = 5.20, p = .028, η_p^2 = .11) was also found where participants looked at the avatar more in the gaze ignored condition (M = 2605, SD = 2282) than the gaze followed condition (M = 2097, SD = 1757). No significant interaction between JA condition and group was found (F(1,42) = .00, p = .984).

Effect of image type

Due to the uneven presentation of image types in the gaze followed and ignored conditions for 22 ASD participants, viewing times for each individual image type AOI were calculated as a proportion of total viewing time for the specific image type. Mean proportion viewing times and standard deviations can be found in table 3.23.

Table 3.23.

AOI proportion viewing times per image type, all participants who completed experiment 2.2

		ASD group (N=21)			TD group (N=23)		
JA cond.	AOI	Abstract	Face	House	Abstract	Face	House
Gaze followed	Target	63.18 (17.23)	60.72 (15.38)	65.16 (16.19)	74.66 (22.25)	73.19 (21.96)	76.12 (20.50)
	Non-target	23.26 (12.41)	21.68 (11.90)	22.23 (11.06)	18.62 (16.88)	20.76 (19.18)	16.77 (14.96)
	Avatar	13.56 (10.88)	17.60 (15.83)	12.61 (10.91)	6.72 (7.02)	6.05 (6.05)	7.11 (7.48)
Gaze ignored	Target	40.67 (21.62)	41.61 (24.28)	43.98 (21.89)	63.01 (31.33)	59.84 (27.03)	64.99 (30.57)
	Non-target	40.52 (18.29)	41.60 (24.22)	38.12 (21.18)	28.40 (27.56)	31.12 (23.07)	26.40 (24.61)
	Avatar	18.81 (12.50)	16.80 (14.46)	17.90 (15.28)	8.59 (10.31)	9.04 (9.14)	8.61 (9.42)

To investigate the effect of image type and joint attention condition on AOI viewing times, separate 2 (group, ASD/TD) × 2 (JA condition, gaze followed/ignored) × 3 (Image type, abstract/face/house) mixed ANOVAs were conducted for the AOIs.

Target images

Target viewing time data for the TD group demonstrated negative skew. Transformations did not eliminate this skew so the original data were used for the analysis. The ANOVA again revealed a significant main effect of JA condition ($F(1,42) = 20.03$, $p < .001$, $\eta_p^2 = .32$) and group ($F(1,42) = 8.23$, $p = .006$, $\eta_p^2 = .16$). The main effect of image type was also significant ($F(1,42) = 3.93$, $p = .023$, $\eta_p^2 = .09$), Bonferroni corrected pairwise comparisons suggested no significant differences between viewing times to abstract target images and face images ($p = .820$) and abstract images and house images ($p = .177$). Participants spent significantly less time looking at face images than house images ($p = .045$). No interactions reached significance (all $F \leq 1.46$, $p \geq .234$, $\eta_p^2 \leq .03$).

Non-target images

Viewing time data for the non-target images were positively skewed for the TD group. Transformations did not eliminate the skew so the original data were used for analysis. The ANOVA again suggested a significant main effect of JA condition ($F(1,42) = 14.93$, $p < .001$, $\eta_p^2 = .26$) and group ($F(1,42) = 3.09$, $p = .086$, $\eta_p^2 = .07$) and no main effect of image type ($F(2,84) = 2.48$ $p = .09$). No interactions reached significance (all $F \leq 1.18$, $p \geq .284$, $\eta_p^2 \leq .03$).

Avatar

Viewing time data to the avatar were positively skewed, transformations did not remove this skew so the original data were used for analysis. The ANOVA revealed a significant main effect of group (F(1,42) = 8.44, p = .006, η_p^2 = .17), where the ASD group looked at the avatar for longer than the TD group. There was also a significant main effect of JA condition (F(1,42) = 7.67, p = .008, η_p^2 = .15), where participants looked at the avatar significantly more in the gaze ignored condition. There was also a significant three-way interaction between JA condition, image type and group (F(1,42) = 4.53, p = .014, η_p^2 = .09). No other main effects or interactions were significant (all $F \leq 1.89$, $p \geq .157$, $\eta_p^2 \leq .04$). To further investigate the significant three-way interaction between JA condition, image type and group, two 2 (JA condition, RJA/IJA) × 3 (Image type, abstract/face/house) ANOVAs were conducted for the ASD and TD groups separately.

ASD group

The ANOVA for the TD groups' non-target image viewing times suggested no significant main effect of JA condition (F(1,20) = 3.65, p = .071) or image type (F(2,40) = .743, p = .482). There was a significant interaction between JA condition and image type (F(2,40) = 3.65, p = .035, η_p^2 = .15). Bonferroni corrected pairwise comparisons suggested significantly greater viewing of the avatar during the gaze-ignored condition than the gaze followed condition when abstract (p = .023) and house (p = .025) images were shown. For face images, there was no difference in avatar viewing between gaze followed and gaze-ignored conditions (p = .749).

TD group

The ANOVA for the TD group suggested a significant main effect of JA condition (F(1,22) = 4.41, p = .047, η_p^2 = .17) where TD participant's viewed the avatar for longer in the gaze ignored condition. No significant main effect of image type (F(2,44) = .084, p = .92). No interaction between JA condition and image type was found (F(2,44) = .703, p = .50).

3.5 Discussion

This study used a gaze contingent avatar to investigate the effect of joint attention on recognition memory for referent images in children with and without ASD. In experiment 2.1 the children followed and directed the avatar's gaze to one of two placeholders to emulate both RJA and IJA. In experiment 2.2 the children chose which placeholders to view and their gaze shifts were either followed or ignored by the avatar. Participants' memory for target images that appeared in the placeholders was then tested. This was in the hope of uncovering any differences in the impact RJA and IJA may have on the depth of processing of the referent image in general and betweenASD and TD children. Participants' eye movements were also recorded to investigate overall viewing strategies during the critical trial period where the target image was shown. Consistent with previous findings from experimental literature comparing RJA and IJA (Kim & Mundy, 2012; Mundy et al., 2016) it was anticipated that TD children would show enhanced recognition memory for target images when they directed rather than followed the avatar's gaze to the target in experiment 2.1 and when the avatar followed rather than ignored their gaze shifts in experiment 2.2. This effect was not expected for the ASD group.

Experiment 2.1.

Analysis of recognition memory for target images in experiment 2.1 revealed similar levels of encoding in RJA and IJA conditions for both groups. When the effect of image type was investigated, recognition memory was poorer overall for face images than for houses and abstract patterns. Memory for abstract images was also enhanced in the RJA condition compared to the IJA condition. Overall, these findings were contrary to expectations, and contrary to findings using a similar paradigm where typically developing adults (Kim & Mundy, 2012) and children, but not children with ASD (Mundy et al., 2016), demonstrated enhanced recognition memory for target images encoded during IJA compared to RJA. The facilitative effect of IJA was not found for either of the groups in the current study and participants' performance on the memory task was not affected by JA condition.

Closer inspection of viewing times to the target images is useful in explaining this finding. Both participant groups viewed target images for significantly longer in the RJA condition than the IJA condition. This suggests that participants did not have to view the target images for as long during the IJA condition to achieve the same level of performance in the memory task as they did in the RJA condition. This may reflect a lower time threshold for object processing and encoding in the IJA condition than the RJA condition. Although great care was taken in this study to control for viewing times, with opportunities for target viewing as similar as possible between the RJA and IJA conditions, this did not guarantee continued fixation on the target images and did not lead to comparable target viewing times between the JA conditions. It must also be noted that the TD group spent slightly but significantly less time overall viewing the screen in the IJA condition. Both previous studies conducted by Mundy and colleagues (2012; 2016), where target images were also presented for 1000ms, reported no differences in target viewing times between JA conditions when the target presentation was yoked with participants' placeholder fixation. The disparity in target viewing times between JA conditions in the current study instead suggests that different visual strategies were employed or necessitated for each JA condition. Although not affecting target image recognition, the other on-screen AOIs may have been more distracting for participants in the IJA condition. Alternatively, due to quicker target image encoding relative to the RJA condition they may have had more time to explore the screen here. Indeed, increased viewing times to target images was associated with greater recognition memory and increased viewing times to non-target images was associated with poorer recognition memory. Further analysis of the gaze data also suggested that participants spent more time viewing non-target images and the avatar in the IJA condition compared to the RJA condition. In the IJA condition participants had to wait for the avatar to complete his gaze shift before the image appeared. Also, this condition involved an uninformed gaze selection. This may have made participants more curious about the image that appeared in their unselected placeholder. Interestingly, the TD group showed increased viewing times to non-target face images relative to non-target house and abstract images, suggesting non-target face images attracted their attention more. This viewing time data reflects their lower memory accuracy for target face images than the other image types. Image type did not have an effect on target or non-target image viewing times for the ASD group.

Increased looking times to the avatar in the IJA condition may also reflect the fact that IJA is more intentionally declarative and communicative than RJA (Mundy et al., 2007). During the IJA condition, it may have been intuitive for participants to monitor whether they had captured the attention of the avatar and successfully guided his attention to the appropriate placeholder. This would be consistent with the use of ‘check back looks’ included in the model of joint attention proposed by Carpenter et al. (2011).

Overall, in experiment 2.1 the ASD group performed more poorly in the memory task than the TD group. This was reflected in the different viewing times between the groups. This highlights the different allocations of attention between the groups and suggests a less task focused viewing strategy from the ASD group. This is surprising when considering some visual paradigms highlight the strength of detail-focused attention in ASD populations (e.g. the embedded figures task). However, the finding of reduced looking time to the referent image in the ASD group when following the avatar’s gaze concurs with previous studies demonstrating that individuals with ASD look less at a gazed at object than their TD peers (Fletcher-Watson et al., 2009; Freeth et al., 2010; Riby, et al., 2013).

Experiment 2.2.

For experiment 2.2, only 10 ASD participants performed at above chance level. When these higher performers were compared with their TD matches the avatar’s response to the participants’ gaze shifts had no effect on their recognition memory for the target images. Performance on the memory task for these participants was comparable when the avatar followed their gaze shifts to their chosen placeholder to view the target and when the avatar ignored their gaze shifts and instead looked at the opposite placeholder and the non-target image. Furthermore, no significant group differences in target detection accuracy were found. This suggests that where participants perform well at this task (above chance level), IJA may not enhance the processing of the referent object. Consistent with the findings from experiment 2.1, recognition memory for these participants was poorer overall for target face images than target abstract and house images.

Analysis of the number of non-target hit responses for the participants who performed the task at above chance level also suggested no effect of JA condition for either group. The ASD group however, reported recognising significantly more non-target images than the TD group. This was with the exception of non-target face images, which were responded to with a similar number of hits from each group. This suggests that, when considering this small group of participants, the task was more difficult overall for participants with ASD. The increased number of hits for non-target images here may also suggest that the non-target images were more distracting for them than the TD group. However, it seems that recognising face images was just as difficult, or the face non-target images were just as distracting for both groups. It must be noted here that although unbalanced presentation of the images for some in the ASD group meant that not all ASD participants viewed the same amount of face images per JA condition, they did see the same overall number of faces, houses and abstract images as all other participants. However, when considering the findings around image type, caution should be taken because the unbalanced stimuli presentation may have obscured any interaction between image type and JA condition that may have been observed had this error not occurred.

A large number of participants performed at, or below chance level for experiment 2.2, subsequent analyses were therefore conducted with all of the ASD participants who completed the task and their TD controls, including those who performed below chance level. When all of these participants were considered for analysis, a different pattern of results emerged. Here, target recognition was significantly greater in the gaze-followed condition than the gaze-ignored condition. At first glance, this result seems consistent with the hypothesis that recognition memory may be enhanced when initiation of a gaze shift is responded to and joint attention to the referent image occurs. However, further analysis suggested that responses to non-target images were also affected by JA condition. As anticipated, significantly fewer hits for non-target images than target images were found in the gaze-followed condition overall. Conversely and unexpectedly, the difference between target and non-target hits was not significant in the gaze-ignored condition suggesting poor task performance in this condition overall. Furthermore, more non-target images and fewer target images were responded to with “yes” responses in the gaze-ignored than the gaze-followed condition. This suggests that when the avatar ignored the participant’s gaze and looked to the non-target image, this may have caused participants to report to remember these as target images. This disparity from expected performance was more apparent in the ASD group. The ASD group responded with a comparable number of hits to target and non-target images overall, suggesting a reduced ability to distinguish target images from non-target images during the task. This is likely to have contributed to the ASD group’s poor performance at the task, particularly in the gaze-ignored condition, and therefore limits the conclusions that can be made about their seemingly better target recognition memory in the gaze-followed condition. Conversely, the TD group responded with significantly more “yes” responses to target images than non-target images overall suggesting better performance of the task. On the whole, the memory task data suggests that for those performing below chance level at experiment 2.2, the appearance of the non-target images and the avatar's gaze towards them may have interfered leading to increased "yes" responses for non-target images and reduced target hits in the gaze ignored condition, particularly for the ASD group. Alternatively, this pattern of findings could reflect a response strategy of random "yes" responses leading below chance performance for identification of target images. This pattern of increased responses for non-target hits was also apparent in the ASD group who performed at above chance level when compared to their TD peers in a separate analysis. Unfortunately due to the design of experiment 2.2 it was not possible to calculate a d-prime or beta value that may have allowed for a more sensitive measure. To unpick these findings and further understand how participants completed this task it will be useful to examine the gaze data.

Analysis of the gaze data for participants who performed above chance suggested that the TD groups' viewing times for target images and non-target images did not differ between the gaze followed and gaze ignored conditions. Conversely, the ASD group (those who performed above chance) viewed target images for less time and non-target images for a longer time in the gaze-ignored condition than the gaze followed condition. When the gaze data for all participants (including those who scored below chance) was considered, participants from both groups spent significantly more time viewing target images and less time viewing non-target images in the gaze-followed condition than the gaze ignored condition. This suggests that the non-target images may have been more interesting when the avatar was viewing them than when he was not. Due to the reported problems with joint attention in ASD this is a surprising finding and contrary to our expectations for the

ASD group. It was anticipated here that the gaze direction of the avatar would be less influential on the attention of the ASD participants than the TD participants. However, in this task the TD group who performed well may have interpreted the avatars gaze direction as irrelevant to the task goal and they may have adopted a strategy where the avatars focus of attention was irrelevant to the task and more easily ignored. Regardless of where the avatar looked in experiment 2.2, the participant was asked to remember the image in the placeholder that they chose to view. In experiment 2.1 the participants followed the avatars gaze to the target and when they made a target directed gaze shift it was always reciprocated. This meant the interactions with the avatar were always relevant and directly linked to the objective and the continuation of the task. This could have made participants feel like they were working together more with the avatar in experiment 2.1 thus increasing the avatars social presence in experiment 2.1 relative to experiment 2.2. In experiment 2.2 participants looked more at the non-target images when the avatar viewed them. However, this may also just be evidence of an overall less task-focused approach as also demonstrated in experiment 2.1.

Inspection of viewing times to the avatar suggested that the ASD group showed longer viewing times to the avatar than the TD group overall. Both groups also looked for longer at the avatar in the gaze ignored condition. When the avatar did not follow the participant’s gaze they looked back at him for longer than when he did follow their gaze. This echoes findings from an experimental paradigm developed by Swanson and Siller (2012; 2013; 2014) to investigate spontaneous gaze following. In their paradigm eye movements are recorded as participants are presented with video footage of a woman’s face in the centre of the screen. The face either looks towards (congruent) or away from (incongruent) a subsequently appearing cartoon target (note, unlike the current study only one possible referent image is presented). Comparing looking times between the congruent and incongruent condition to the face and the target revealed that children (Swanson & Siller, 2012) and adults (Swanson & Siller, 2014) with fewer reported features of the broader autism phenotype (BAP) demonstrate significantly longer viewing times for the face and shorter viewing times for the target in the incongruent condition compared to the congruent condition. Interestingly this disparity in viewing times between the conditions is considerably attenuated in adults and children with greater reported features of the BAP and for children with ASD (Swanson & Siller, 2013). The differences between TD and ASD groups were only uncovered when attention allocation was measured as duration of first fixation. The authors suggested that the children were more likely to check the face when it looked away from the target as it had violated their expectations of viewing the target. This seems also to have been the case in the current experiment 2.2. The avatar was observed for longer when he did not follow the participant's gaze. This action may have violated the children's expectations and indeed social norms for an interactive social partner (Bayliss et al., 2013). Furthermore, a face that does not look the way participants anticipate may be more difficult to interpret (Goldberg & Kotval, 1999; Swanson & Siller, 2013). Here both groups looked back to the avatar for longer when their gaze shift was ignored. The ASD group looked back to the avatar for longer than the TD group, which may suggest the ASD group had more difficulty with this cue.

Overall, in experiment 2.2 the ASD group performed more poorly in the memory task than the TD group. Where both groups of participants performed poorly, their increased viewing time to the avatar and non-target images seemed to contribute to this poorer performance., The ASD group in particular demonstrated a higher number of hits for non-target images. Similarly to the findings from experiment 2.1, during the critical target presentation period, the ASD group spent less time than the TD group viewing target images and more time viewing the avatar and non-target images. This highlights the different allocation of attention between groups. Whether this is due to overall attention difficulties with staying on task, problems with interpreting the avatar's gaze, or the propensity not to use gaze cues to interpret another's actions is unclear.

Taken together, the findings of this study did not fully support the hypotheses. Contrary to previous findings (Kim & Mundy, 2012; Mundy et al., 2016) IJA did not enhance recognition memory for referent images compared to RJA in the typically developing group and no differences in the effect of JA between the ASD and TD groups were found. This disparity in findings could be due to the differences in the paradigm used in the current study and the previous studies. Here, a novel and portable laptop and eye tracker setup was used instead of a more immersive, virtual reality paradigm with a headset (Kim & Mundy, 2012; Mundy et al., 2016). Immersion has been linked with a sense of 'presence', or with the feeling of being part of a virtual environment. This has often been assumed to enhance task engagement and performance, although these assumptions are controversial (Miller & Bugnariu, 2016; Slater et al., 1996). The effects of increased immersion in virtual navigation and procedural memory tasks, for example, have elicited mixed findings (e.g. Bowman et al., 2009, Santos et al., 2009). However, studies using virtual environments with low, medium and high levels of immersion have been used to teach social skills in ASD and have successfully detected differences in performing social tasks between those with and without ASD (Alcorn et al., 2011; Miller & Bugnariu, 2016). The level of immersion is therefore unlikely to contribute to differences in findings between the studies. Also novel to the current study, the avatar made a head turn in conjunction with a gaze shift. This made the presentation of the avatar's gaze shift longer than that of the previous paradigm (640ms vs. 300ms).

Interestingly, viewing times to the target images in the current study differed between the RJA and IJA condition when recognition memory did not, yet in the paradigm used by Kim and Mundy (2012) and Mundy et al. (2016), viewing times were comparable between the conditions but recognition memory was not. The methodology of the current study aimed to mirror the RJA and IJA conditions, making the order of events leading up to the target presentation period and the target presentation period itself as comparable between conditions as possible. This meant that the children were asked to view an empty placeholder in the IJA condition until the avatar had followed their gaze. This was also with the aim to remove any additional visual distraction from the avatar that the gaze shift and head turn may have caused had the target image been presented as soon as the participant viewed the placeholder. Although this method allowed for the RJA and IJA trials to progress identically, the expectation that this would equate to similar target viewing times was not realised. Furthermore is it possible that viewing a blank placeholder for longer than 300ms may diminish any facilitative effect of IJA. The referent image may need to be visible when joint attention is being initiated for the effect of IJA to truly materialise. It must be noted however that the limited knowledge on IJA, the novelty of this technique, and its use in a paradigm like this means that it is not yet clear whether this is the case. Future studies should incrementally adjust the target presentation time, the duration of the gaze shift and the order of events to resolve the potential effects leading to contrasting findings here.

Mostly, the gaze contingency element of the task worked well in the current study. In the IJA condition the avatar was programmed to reliably gaze at the participants' chosen placeholder and the participants were explicitly instructed and reminded only to choose one placeholder to view. However, due to the single monitor set up there was no way for the experimenter to monitor participants' eye movements throughout the task. There was also more variability in the time taken for the image stimuli to be presented in the IJA condition. This could have occurred due to eye tracker flicker. However, if the eye tracker lost the participant's point of gaze completely, the task was automatically terminated. This variability may also have been due to the more self-paced nature of the IJA task. Participants were able to take as long as they wished to choose their target placeholder, whereas the time the avatar took was consistent. Consequently the differences in timing between the RJA and IJA conditions likely varied between participants and even within participants' trial blocks. Creative methodology to more strictly control the self-paced nature of IJA should be implemented in this paradigm for future research. This may be done through the use of explicit prompts, however it will be important to avoid or unpick any confounding effects this may cause.

Overall, the demands of this task were quite high and several participants were initially removed from the analysis for poor task performance. All participants who completed the task at above chance level had IQ scores of above 70. This suggests that this task may be more suitable for moderate to higher functioning participants. The participants in this study were lower functioning than the high functioning autistic children (mean IQ = 103.6) who took part in the study by Mundy et al. (2016). Although the viewing time data for participants performing above chance level suggested that participants with ASD were less task focused (i.e. less focus on the target image) the analysis demonstrated higher viewing times and a greater number of hits for target images than non-target images for both groups. This suggests that although attention was allocated to the avatar, non-target images, and elsewhere on the screen, these participants were able to follow the instructions and complete the task. However, it must be noted that participants with ASD consistently viewed target images for significantly less time than the TD group. Furthermore, when all participants who performed below chance were included in the analysis for experiment 2.2, the memory task data suggested that they did not distinguish target from non-target images in the gaze-followed condition. This suggests that the task may have been too difficult for some children, especially those with ASD. These participants appeared to be more distracted by the avatar and the non-target image, to the detriment of their task performance. In general the decreased attention to target images and increased attention to the avatar and non-target images in the ASD group compared to the TD group, suggests that participants with ASD may need more time to take in the scene and interpret the reactions of the avatar.

Overall, these findings make a substantial contribution to the development of experimental methods for studying JA in children with ASD and for studying JA more generally. Specifically, these findings advance the study of IJA, which has so far been under researched due to methodological barriers. As such, the current findings further address and establish some of the methodological challenges of studying IJA. Here we have demonstrated that children with ASD can engage successfully with a virtual character in an interactive RJA and IJA context, however, some care should be taken in considering the effect of simultaneously presented stimuli. This will be valuable for the development of virtual socially assistive media for children with ASD.

Chapter 4: Experiment 3

Responding to and initiating joint attention with a virtual character in adults with higher and lower levels of autistic traits

4.1 Introduction

The findings from study two of this thesis suggested similar recognition memory for referent images encoded in RJA, IJA, and conditions where IJA was not reciprocated in children with and without ASD. This is contrary to previous findings of enhanced recognition memory for images encoded under simulated IJA in typically developing adults (Kim and Mundy, 2012; Kim, Jang & Kim, 2015) and more recently, in typically developing children (Mundy et al., 2016). This difference in findings could be explained by different attention allocation to the on screen AOIs and reduced viewing times to target images in the IJA condition compared to the RJA condition. Participants in study two were also a slightly lower-functioning group than those who have completed a similar task in the only previous experimental study investigating both RJA and IJA in children with and without ASD (Mundy et al., 2016). The differences found in attention allocation between the conditions in study two may therefore be inherent to lower-functioning children or to the presentation of the JA conditions used in this particular methodology. Further study with this experimental paradigm is required to begin to explain any differences between study findings. The current study will therefore test the performance of a group of typically developing adults using the same joint attention tasks used in study two of this thesis. Here, adult participants are expected to elicit more robust task performance than the child participants.

This study will investigate recognition memory for target images viewed under RJA and IJA conditions in typically developing adults to explore differences between the two types of joint attention. Participants' levels of self-reported autistic traits will also be measured and task performance will be compared between those with higher and lower levels of autistic traits. This will further test the continuum approach to the study of ASD and determine whether any lack of modulation in IJA compared to the RJA found in ASD participants (Mundy et al., 2016) is apparent in those with higher levels of autistic traits. This is in an effort to elucidate any differences in processing during RJA and IJA that may be attributable to autistic traits. Understanding these processes will bring greater clarity about what differences may be expected in RJA and IJA and to what extent variation may be expected in the typically developing population. Furthermore, given the novelty of studying IJA in this way it is important to further test this paradigm on typically developing adults.

Previous research with typically developing adults has shown individual differences in gaze cueing tasks associated with autistic traits (e.g. Bayliss & Tipper, 2005; Bayliss, DiPelligrino & Tipper, 2005; Hudson, Nijboer & Jellema, 2012; Zhao, Uono, Yoshimura & Toichi, 2015) but less is known about how autistic traits affect processing of the referent object in RJA and IJA. Previous studies comparing RJA and IJA in the typically developing adult population suggest that recognition memory for referent images viewed under IJA conditions is enhanced when compared with RJA conditions (Kim & Mundy, 2012; Kim, Jang & Kim, 2015). Recently, IJA has also been associated with more efficient detection of a target stimulus when the target appears on a face that has followed ones gaze shift compared to when it does not reciprocate a gaze shift (Edwards et al., 2015). Furthermore, this effect was weaker in those with higher levels of autistic traits. This suggests that initiating a gaze shift which was subsequently followed did not modulate the attention of those with more ASD associated traits as strongly as those with fewer autistic traits, who showed a facilitative effect of IJA for the task. Overall, this evidence suggests an attentional system that can establish joint attention efficiently. This system also appears to facilitate information processing, perhaps particularly when joint attention is self-initiated (Kim & Mundy, 2012). The emerging evidence that this may be attenuated with higher levels of autistic traits is intuitive when considering the continuum view of ASD and the problems that individuals with ASD have with joint attention. It is not yet clear how autistic traits would affect recognition memory of the referent object under RJA and IJA conditions. The following study aims to investigate this to further clarify typical joint attention processing and capture any differences found in in typical populations that may be part of the broader autism continuum. Individual differences found here may reflect developmental differences in social cognition.

The current study took a similar structure as study two of this thesis and used identical joint attention tasks. Participants were split into groups with higher and lower levels of autistic traits as measured by the AQ. Participants completed joint attention experiments 1 and 2 in one session. For experiment 3.1, participants followed (RJA) and directed (IJA) an avatars gaze shift to one of two placeholders and were asked to memorise the image that appeared in the relevant placeholder. It was expected that the group with lower AQ scores would show greater recognition memory for images shown in the IJA condition than the RJA condition, however this effect of JA condition was expected to be reduced in the group with higher AQ scores. The group with high AQ scores were expected to show similar recognition memory for the images in the RJA and IJA conditions. For experiment 3.2, participants were asked to choose one of the placeholders to view and memorise the image that appeared, the avatar followed their gaze for half of the trials (gaze-followed condition) and ignored their gaze for the other half of the trials (gaze-ignored condition). It was hypothesised that the group with lower AQ scores may show greater recognition memory for images that elicited a reciprocal gaze shift from the avatar compared to those where the avatar ignored their gaze. This effect was not expected in the high AQ group or was expected to be significantly reduced.

4.2 Method

Participants

Participants were recruited from the University of Strathclyde undergraduate and postgraduate student population, the School of Psychological Sciences and Health participant pool and online community fora. 274 participants completed an online version of the AQ questionnaire. Questionnaires were scored using the binary scoring method described in study 1, chapter 2. Scores ranged from 3 to 46 (M=16.46, SD= 7.38). All participants with a score of 12 or below (N=87) and 19 or above (N=94) were contacted with an invitation to the lab to complete the Corsi block and joint attention tasks. This led to 38 participants with lower AQ scores and 38 participants with higher AQ scores taking part in the full study. Figure 4.1 shows a frequency histogram for participant's AQ scores and table 4.1 shows the groups' mean age and AQ scores. This histogram clearly demonstrates two distinct groups with a gap between the higher and lower scoring participants. These participants received course credits or a £5 high street shopping voucher for their participation in the study.

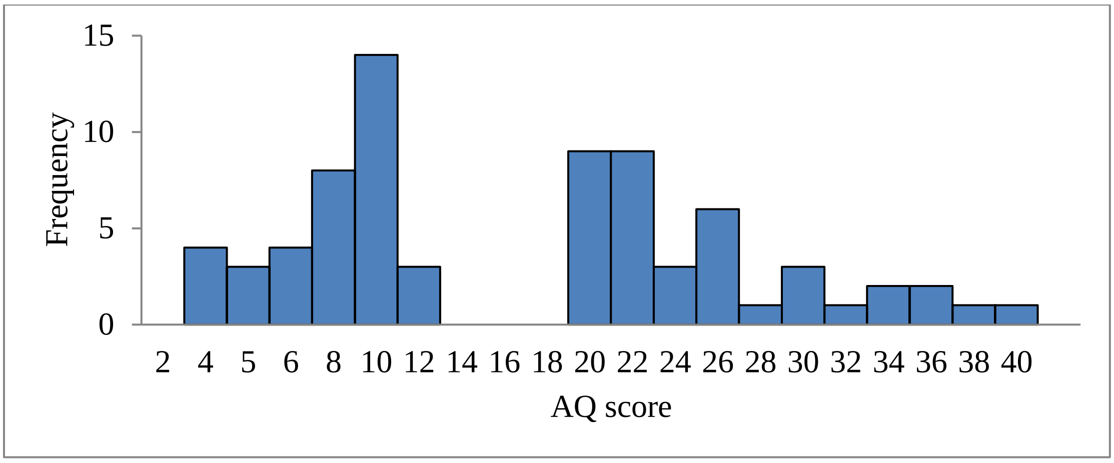

Figure 4.1. Frequency histogram of participant AQ scores, experiment 3

Table 4.1.

Participant characteristics, experiment 3

AQ group	Mean AQ score (SD)	Mean age in yrs. (SD)	Sex, M/F
Low	7.81 (2.47)	29.12 (11.26)	3/35
High	24.97 (5.80)	23.88 (9.21)	9/29

Materials

The computerised version of the Corsi blocks task (Kessles et al., 2000) was used to measure visuo-spatial short term working memory. Joint attention experiment 1 and 2 from study 2 were also used to measure image recognition memory under different joint attention conditions. The image stimuli and virtual character were presented as described in chapter 3, using the same setup and identical software and hardware.

Procedure

Participants first completed the Corsi blocks task; this followed the same procedure as described in study 2. Participants then completed both joint attention experiments 1 and 2. The order of presentation of these tasks was fully counterbalanced. Before each task, participants completed the calibration procedure and at least 4 task practice trials. The procedure for each task was identical to those described in chapter 3, study 2. The whole lab based session took approximately 45-60 minutes to complete.

4.3 Results

Corsi blocks task

Corsi block scores were calculated in the same way as in study 2. Means and standard deviations are shown in table 4.2.

Table 4.2.

Corsi blocks scores, experiment 3

	High (N=38)	Low (N=36)
Total score	58.08 (19.18)	56.78 (23.66)
Total correct trials	8.95 (1.41)	8.83 (1.90)
Block span	6.34 (1.21)	6.22 (1.45)
Memory span	5.49 (0.71)	5.44 (0.94)

Independent samples t-tests revealed no significant differences between the groups' total scores ($t(72) = 0.26$, $p = .795$), block span ($t(72) = 0.75$, $p = .459$), number of correct trials ($t(72) = 0.29$, $p = .770$) or memory span ($t(72) = 0.22$, $p = .827$). Overall, these results suggest comparable performance on the Corsi blocks task for the high and low AQ groups.

Joint attention tasks

Memory test responses and gaze data for experiments 3.1 and 3.2 were inspected for abnormalities and outliers and where appropriate, transformations were applied. Initial screening of the memory test and gaze data revealed skew in some experimental conditions that was not eliminated by transformations. Parametric tests are considered to be robust to violations of assumptions (Clark-Carter, 1998) so, as in study 1 and 2, parametric analyses are reported here to allow for interaction effects to be investigated. Precautionary non-parametric tests were also conducted, results of which were consistent with the findings from the reported parametric analyses.

4.3.1 Joint attention experiment 3.1

Technical problems with the computer programme prevented two participants from the low AQ group from completing experiment 2.1. (High AQ group: N=38, low AQ group: N=36).

Experiment 3.1 gaze data analysis

Four further participants from the low AQ group and five participants from the high AQ group were removed from the gaze data analysis due to eye tracker error. This included missing trials and reduced time of gaze recording. A further 3 participants from the high AQ group and 2 from the low AQ group were identified as outliers with low on-screen percentage viewing times (z-scores >3.29). These participants were also removed from the analysis. This left 30 participants' data for each AQ group included in the gaze data analysis. All remaining participants had on screen percentage viewing times of ≥ 91.5% for each JA condition.

Table 4.3 shows the percentage of time for the target presentation period that the participants' point of gaze was captured on the screen. Independent samples t-tests suggested no differences between the groups on-screen percentage in the RJA condition ($t(58) = -1.40$, $p = .889$). For the IJA condition Levene's test indicated violation of the assumption of equality of variance therefore degrees of freedom were adjusted accordingly. The high AQ group demonstrated a slightly (1.31%) but significantly higher on screen percentage looking time than the low AQ group for the IJA condition ($t(46.81) = 2.17$, $p = .035$, $d = 0.63$). Individual group analysis using paired samples t-tests revealed no significant differences between the RJA and IJA conditions for the high AQ group ($t(29) = -1.59$, $p = .123$) or the low AQ group ($t(29) = 1.10$, $p = .280$)

Table 4.3.

Target presentation on screen %, experiment 3.1

	RJA % on screen	IJA % on screen
High AQ group (N=30)	98.19 (2.30)	98.99 (1.68)
Low AQ group (N=30)	98.27 (2.07)	97.68 (2.86)

Viewing time data for the non-target images and the avatar demonstrated floor effects suggesting that most participants did not look at these AOIs during the target image presentation period. Table 4.4 shows the number of participants from each group who did not look at these AOIs (N at floor) and the mean of the total viewing times to these AOIs from the remaining participants.

The few participants who looked at these AOIs and the small viewing time values for those who did suggests that the adult participants did not spend a significant amount of time looking away from the target image when it was presented. For this reason, only the target viewing times were analysed.

Table 4.4.

Non-target AOIs, experiment 3.1

		High AQ group		Low AQ group	
		N. at floor (total N =30)	Remaining participants mean viewing time	N. at floor (total N=30)	Remaining participants mean viewing time
RJA	Non-targets	22	71 (160)	27	30 (110)
	Avatar	17	54 (119)	14	91 (156)
IJA	Non-targets	20	252 (524)	24	47 (150)
	Avatar	13	140 (205)	15	83 (149)

Target viewing times

Data for the target viewing times demonstrated negative skew. A square root transformation completely eliminated this skew, so the transformed data were used for analysis. A 2 (group, high/low) × 2 (JA condition, RJA/IJA) mixed ANOVA with group as the between-groups factor revealed no significant main effect of JA condition ($F(1,58) = .232$, $p = .632$) or group ($F(1,58) = .803$, $p = .374$) and no significant interaction between group and JA condition ($F(1,58) = .005$, $p = .943$). This suggests equivalent viewing times for target images between the groups and JA conditions, means and standard deviations can be found in table 4.5.

Table 4.5.

Target viewing times, experiment 3.1

	RJA target viewing time	IJA target viewing time
High AQ group (N=30)	23004 (1444)	23079 (1129)
Low AQ group (N=30)	22734 (1350)	22830 (1326)

Joint attention experiment 3.1 memory test results

To analyse responses from the memory task, *d'* and β was calculated in the same way as in study 2.1. See table 4.6 for participants' mean *d*' and beta values for the RJA and IJA conditions.

Table 4.6.

Mean d' and β values for RJA and IJA, experiment 3.1

	RJA		IJA	
	High AQ (N=38)	Low AQ (N=36)	High AQ (N=38)	Low AQ (N=36)
d'	2.88 (0.78)	2.94 (0.78)	2.86 (0.76)	2.86 (0.71)
β	-0.67 (0.93)	-0.65 (0.93)	-0.68 (0.83)	-0.67 (0.87)

Effect of JA condition

A 2 (JA condition, RJA/IJA) × 2 (group, high/low) mixed ANOVA on the *d'* scores, with 'group' as the between-groups factor revealed no significant main effect of JA condition ($F(1,72) = .398$, $p = .530$) or group ($F(1,72) = .036$, $p = .851$), and no interaction between JA condition and group $F(1,72) = .157$, $p = .693$).

The same analysis for beta values revealed no significant main effect of JA condition ($F(1,72) = 0.03$, $p = .871$) or group ($F(1,72) = .006$, $p = .939$), and no interaction between JA condition and group $F(1,72) = .007$, $p = .935$).

Effect of Image type

One participant from the low AQ group exhibited an extreme, low, *d'* score (z-score >3.29) for abstract images in the RJA condition. For this analysis, their score was replaced with the mean score minus two times the standard deviation (Field, 2008). The mean *d*' for each image type in the RJA and IJA conditions are presented in table 4.7.

A mixed 2 (JA condition, RJA/IJA) × 2 (AQ group, high/low) × 3 (image type, abstract, face, house) ANOVA with 'AQ group' as the between-groups factor showed no significant main effect of JA condition ($F(1,72) = .057$, $p = .812$), group ($F(1,72) = .063$, $p = .803$), or image type ($F(2,144) = 2.47$, $p = .088$) on the *d'* scores. No interactions reached significance (all $F \leq 1.49$, $p \geq .230$, $\eta_p^2 \leq .01$).

Table 4.7.

Mean d' scores for image type in RJA and IJA, experiment 3.1

Attention condition	Image type	High AQ group (N=38)	Low AQ group (N=36)
RJA	Abstract	2.57 (0.70)	2.55 (0.67)
	Face	2.40 (0.72)	2.59 (0.54)
	House	2.41 (0.76)	2.41 (0.79)
IJA	Abstract	2.64 (0.60)	2.50 (0.65)
	Face	2.34 (0.75)	2.45 (0.68)
	House	2.43 (0.69)	2.46 (0.68)

Non-target image analysis

Non-target identification was expected to be very low. Indeed, all participants selected the “yes” response for non-target images at well below chance levels. Two participants in the low group and three participants in the high group were identified as outliers with a higher number of “yes” responses for non-target images in at least one image type condition (z-scores >3.29). Their scores were replaced with the mean plus two times the standard deviation (Field, 2008). The mean number of “yes” responses elicited by non-targets is presented in table 4.8.

Table 4.8.

Mean number of non-target images with "yes" responses, experiment 3.1

JA condition	Image Type	High AQ	Low AQ
RJA	Abstract	0.18 (0.49)	0.33 (0.59)
	Face	0.37 (0.67)	0.23 (0.43)
	House	0.22 (0.51)	0.44 (0.84)
	Overall	0.75 (1.24)	0.97 (1.27)
IJA	Abstract	0.25 (0.52)	0.36 (0.65)
	Face	0.39 (0.68)	0.33 (0.62)
	House	0.39 (0.63)	0.43 (0.73)
	Overall	1.08 (1.30)	1.15 (1.62)

The data were analysed using a 2 (group: high, low) × 2 (JA condition: RJA, IJA) × 3 (image type: abstract, face, house) mixed ANOVA with AQ group as the between groups factor. Mauchly's test indicated that the assumption of sphericity had been violated for the image type factor ($X^2(2) = 8.22$, $p=.016$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\varepsilon = 0.94$). This revealed no significant main effects of JA condition ($F(1,72) = 1.36$, $p = .248$) or group ($F(1,72) =.334$, $p = .565$). There was also no significant main effect of image type ($F(1.80,129.81) = .931$, $p =.388$), and no interactions reached significance (all $F \leq 2.01$, $p \geq .138$, $\eta_p^2 \leq .03$).

Analysis of AQ factors, experiment 3.1

Given that the AQ comprises subscales corresponding to different domains of cognitive atypicality associated with ASD, additional analyses were conducted to investigate any differences between individuals who reported low and high scores for each of the five AQ factors; social skills, attention switching, communication, imagination and attention to detail. Furthermore, the social skills, attention switching, communication and imagination factors were collapsed into an overall social interaction factor suggested by Hoekstra et al. (2008). Both attentional and social cognitive processes are important aspects of joint attention behaviour and deficits in these components may contribute to an explanation of atypical joint attention in ASD (Baron-Cohen, 1995, Dawson et al., 1998, 2004; Mundy & Neal, 2001). The subcomponents of the AQ tap into separate social and attentional preferences (Baron-Cohen et al., 2001; Hoekstra et al., 2008). Breaking down the AQ scores to study each individual factor will further investigate the effect of specific autistic traits on joint attention. This may help to determine whether individual differences in specific cognitive styles associated with ASD have an impact on performance of the joint attention task. Given the heterogeneity of ASD and the suggestion that ASD may comprise fractionable characteristics (Happé & Ronald, 2008), the expression of autistic traits in the general population may be similarly heterogeneous and fractionable. A more detailed investigation of specific autistic traits in the separate domains may therefore help to clarify and extend understanding of JA performance and how this may be affected by specific subclinical traits. A median split was conducted for each factor to split the participant group into high and low scores.

No significant main effects of JA condition, group or image type were found when groups were split by their scores on attention switching (all $F \leq 2.65$, $p \geq .074$, $\eta_p^2 \leq .04$), imagination (all $F \leq 2.99$, $p \geq .088$, $\eta_p^2 \leq .03$), attention to detail (all $F \leq 2.99$, $p \geq .088$ $\eta_p^2 \leq .04$), overall social interaction (all $F \leq 2.56$, $p \geq .081$, $\eta_p^2 \leq .03$) or social skills factors (all $F \leq 1.79$, $p \geq .053$, $\eta_p^2 \leq .04$. Here, the main effect of image type approached significance, $p = .053$, with abstract images eliciting higher *d'* scores than face or house images).

When split by their scores on the communication factor (high group, N=32; low group, N=42), a mixed 2 (JA condition, RJA/IJA) × 2 (Communication group, high/low) × 3 (image type, abstract, face, house) ANOVA with group as the between-groups factor found no significant main effect of JA attention condition ($F(1,72) = .050$, $p = .823$) or group ($F(1,72) = .125$, $p = .725$). A significant main effect of image type was revealed ($F(2,144) = 3.31$, $p = .039$, $\eta_p^2 = .04$), however, Bonferroni corrected pairwise comparisons suggested no significant differences between face and house ($p = 1.00$) or face and abstract images ($p = .113$) and no significant difference between abstract and house images ($p = .070$). The ANOVA also revealed a significant interaction between image type and AQ group ($F(2,144) = 3.20$, $p = .044$, $\eta_p^2 = .04$). However, Bonferroni corrected pairwise comparisons suggested no significant differences in *d'* scores between the low and high groups for abstract ($p = .250$), face ($p = .127$) or house ($p = .638$) images. When the groups were considered separately, no significant differences between image types were found for the low AQ group (all *p* values = 1.00). For the high AQ group, significantly increased memory for abstract images compared to face ($p = .010$) and house images ($p = .032$) was found. No other ANOVA interactions reached significance, (all $F \leq$

.635, $p \geq .532$, $\eta_p^2 \leq .01$). Means and standard deviations of the *d'* scores are presented in table 4.9.

Overall, the results of experiment 3.1 suggest no effect of JA condition on recognition memory for the referent object. Contrary to hypotheses, recognition memory did not differ between the RJA and IJA conditions or between the high and low AQ groups.

Table 4.9.

Mean d' scores per image type. Participants split by AQ communication factor, experiment 3.1

JA condition	Image Type	High AQ group Communication (N=32)	Low AQ group Communication (N=42)
RJA	Abstract	2.61 (0.75)	2.52 (0.63)
	Face	2.39 (0.72)	2.56 (0.57)
	House	2.39 (0.74)	2.42 (0.80)
IJA	Abstract	2.69 (0.61)	2.48 (0.63)
	Face	2.28 (0.78)	2.49 (0.65)
	House	2.38 (0.73)	2.50 (0.64)

4.3.2 Joint attention experiment 3.2

One participant from each group did not complete experiment 3.2 due to unsuccessful eye tracker calibration. Three participants from the high AQ group and two from the low AQ group were also unable to complete the task due to technical problems with the computer programme. Furthermore, three participants from the high AQ group performed at or below chance level for target identification on gaze followed and/or gaze ignored conditions overall. These participants were considered to have been paying insufficient attention to the task and were removed from the subsequent memory task and gaze data analysis (High AQ group, N=31; Low AQ group, N=35).

Experiment 3.2 gaze data analysis

Three further participants from the low AQ group were removed from the gaze data analysis due to eye tracker error, including missing trials and reduced time of gaze recording. One participant from each group was also removed from the gaze data analysis after being identified as outliers demonstrating reduced on screen percentage viewing time. This left a total of 30 participants from the high group and 31 from the low group for the gaze data analysis. All remaining participants had on-screen percentage viewing times of ≥ 87.7% for each JA condition.

Table 4.10 shows the percentage of time during the target presentation periods that the participants' point of gaze was captured on the screen. Independent samples t-tests suggested no differences between the groups in the gaze followed condition ($t(59) = 1.22$, $p = .226$) or the gaze ignored condition ($t(59) = 1.03$, $p = .308$). Individual group analysis using paired samples t-tests revealed no significant differences between the gaze followed and ignored conditions for the high AQ group ($t(29) = 1.20$, $p = .238$) or the low AQ group ($t(30) = 1.30$, $p = .204$).

Table 4.10.

Target presentation on screen %, experiment 3.2

	Gaze followed	Gaze ignored
High AQ group (N=30)	98.89 (2.09)	98.48 (2.79)
Low AQ group (N=31)	98.18 (2.44)	97.74 (2.81)

Viewing time data for the non-target images and the avatar again demonstrated floor effects suggesting that most participants did not look at these AOIs during the target image presentation period. Table 4.11 shows the number of participants from each group who did not look at these AOIs and the mean total viewing times of the remaining participants who did.

Table 4.11.

Non-target AOIs, experiment 3.2

		High AQ group		Low AQ group	
		N. at floor (total N =30)	Remaining participants mean viewing time	N. at floor (total N =31)	Remaining participants mean viewing time
Followed	Non-targets	22	112 (249)	23	56 (181)
	Avatar	18	68 (132)	14	89 (152)
Ignored	Non-targets	21	118 (288)	23	130 (332)
	Avatar	16	102 (164)	13	81 (147)

Again, the few participants who looked at these AOIs and the small values for those who did suggests that the adult participants did not spend a significant amount of time ‘off task’ when the target image was presented. For this reason, only the target viewing times were analysed.

Target viewing times

A 2 (group, high/low) × 2 (JA condition, gaze-followed/gaze-ignored) repeated-measures ANOVA with group as the between-groups factor revealed no significant main effect of JA condition ($F(1,59) = 3.66$, $p = .061$) or group ($F(1,59) = .095$, $p = .758$) and no significant interaction between group and JA condition ($F(1,59) = .152$, $p = .698$). This suggests similar viewing times for target images between the groups and JA conditions. Means and standard deviations can be found in table 4.12.

Table 4.12

Target viewing times, experiment 3.2

	Gaze followed target viewing time	Gaze ignored target viewing time
High AQ group (N=30)	23173 (1354)	22879 (1543)
Low AQ group (N=31)	23023 (1083)	22829 (1382)

Experiment 3.2. Memory test results

As in study 2.2, percentage accuracy target identification was the main variable of interest. One participant from the low AQ group was identified as an outlier for the image type analysis for floor performance for house images in the gaze followed condition. Their score was therefore replaced with the mean score minus two times the standard deviation (Field, 2008). Table 4.13 shows the mean percentage accuracy of participants' correct target identification for each overall attention condition and each image type per attention condition (High AQ group, N=31; Low AQ group, N=35).

Table 4.13.

Mean percentage accuracy for each image type in gaze followed and gaze ignored conditions, experiment 3.2

JA condition	Image Type	High AQ (N=31)	Low AQ (N=35)
Gaze Followed	Overall	82.93 (11.65)	84.64(13.85)
	Abstract	83.87 (13.77)	83.21 (18.18)
	Face	78.63 (19.42)	85.71 (16.37)
	House	86.29 (12.23)	86.19 (17.55)
Gaze Ignored	Overall	84.81 (10.79)	86.07 (11.16)
	Abstract	84.27 (18.81)	85.36 (18.26)
	Face	84.68 (16.99)	87.14 (14.05)
	House	85.48 (13.35)	85.71 (14.27)

Effect of JA condition

A 2 (group: high, low) × 2 (JA condition: gaze followed, gaze ignored) mixed ANOVA revealed no significant main effect of group (F(1,64) = .046, p =.831) or JA condition (F(1,64)= 2.45, p = .123) and no significant interaction between attention condition and group (F(1,64) = .046, p = .831).

Effect of image type

A 2 (group: high, low) × 2 (JA condition: gaze followed, gaze ignored) × 3 (Image type: abstract, face, house) mixed ANOVA revealed no significant main effect of group (F(1,64) =.389, p = .535), JA condition (F(1,64) = 1.94, p =.168) or image type (F(2,128) =.564, p =.570). No interactions reached significance (all $F \leq$ 1.23, $p \geq .296$, $\eta_p^2 \leq .02$)

Non-target images

Two participants from the high AQ group and two from the low AQ group were identified as outliers (z-scores >3.29) with a higher percentage of "yes" responses for non-target images in one or two conditions. For this analysis, their scores for those conditions were replaced with the mean score plus two times the standard deviation (Field, 2008). Table 4.14 shows the mean percentage of "yes" responses for non-target images for each image type in the gaze followed and gaze ignored conditions. The non-target data demonstrated positive skew for both groups. Log transformations completely eliminated this skew so the transformed data were used for analysis.

Table 4.14.

Mean percentage of non-target images with "yes" responses, experiment 3.2

JA condition	Image Type	High AQ (N=31)	Low AQ (N=35)
Gaze Followed	Abstract	6.05 (8.46)	7.14 (11.05)
	Face	4.82 (8.29)	7.86 (12.89)
	House	6.05 (9.05)	7.11 (11.77)
	Total	5.78 (7.27)	7.24 (7.03)
Gaze Ignored	Abstract	6.29 (11.16)	7.14 (9.24)
	Face	5.24 (8.39)	7.52 (10.64)
	House	3.61 (6.54)	5.00 (8.68)
	Total	5.16 (6.73)	6.48 (6.23)

A 2 (group: high, low) × 2 (JA condition: Gaze-followed, Gaze-ignored) × 3 (image type: abstract, face, house) mixed ANOVA on the log transformed data, with AQ group as the between-groups factor revealed no significant main effects of JA condition ($F(1,64)= .264$, $p = .609$) or group ($F(1,64)=.652$, $p = .423$). There was also no significant main effect of image type ($F(2,128)=.582$, $p = .560$), and no interactions reached significance (all $F \leq 1.07$, $p \geq .870$, $\eta_p^2 \leq .02$).

Analysis of AQ factors experiment 3.2

No significant main effects of JA condition, group or image type were found when groups were split by their scores on social skills (all $F \leq 2.69$, $p \geq .106$, $\eta_p^2 \leq .04$), attention switching (all $F \leq 2.01$, $p \geq .161$, $\eta_p^2 \leq .03$), communication (all $F \leq$

3.53, $p \geq .065$, $\eta_p^2 \leq .05$), attention to detail (all $F \leq 1.09$, $p \geq .300$ $\eta_p^2 \leq .02$) or overall social interaction (all $F \leq 2.02$, $p \geq .161$, $\eta_p^2 \leq .03$).

When the groups were split by their scores in the imagination factor (high group, N=23; low group, N=43), a mixed 2 (JA condition, gaze followed/gaze ignored) × 2 (imagination group, high/low) × 3 (image type, abstract, face, house) ANOVA with 'imagination' AQ group as the between groups factor revealed a significant main effect of JA condition ($F(1,64) = 5.47$, $p = .023$, $\eta_p^2 = .08$) and group ($F(1,64) = 7.36$, $p = .009$, $\eta_p^2 = .10$). No significant main effect of image type was found ($F(2,128) = 0.91$, $p = .407$). There was a significant interaction between JA condition and group ($F(1,64) = 9.59$, $p = .003$, $\eta_p^2 = .13$). This interaction is plotted in figure 4.2. No other interactions reached significance (all $F \leq .999$, $p \geq .371$, $\eta_p^2 \leq .02$). Bonferroni corrected pairwise comparisons suggested that for the gaze followed condition, participants with a high AQ score in the 'imagination' factor demonstrated significantly lower accuracy than those in the low AQ group ($p = .001$). No difference between the groups was found in the gaze-ignored condition ($p = .145$). Further Bonferroni corrected comparisons suggested no difference between the two JA conditions for the low AQ group ($p = .523$) but significantly poorer accuracy in the gaze followed condition for the high group ($p = .001$; High AQ group- gaze followed M=76.63, SD = 13.51 and gaze ignored, M = 82.79, SD = 12.56; Low AQ group- gaze followed M = 87.69, SD = 10.68 and gaze ignored M = 86.91, SD = 9.86).

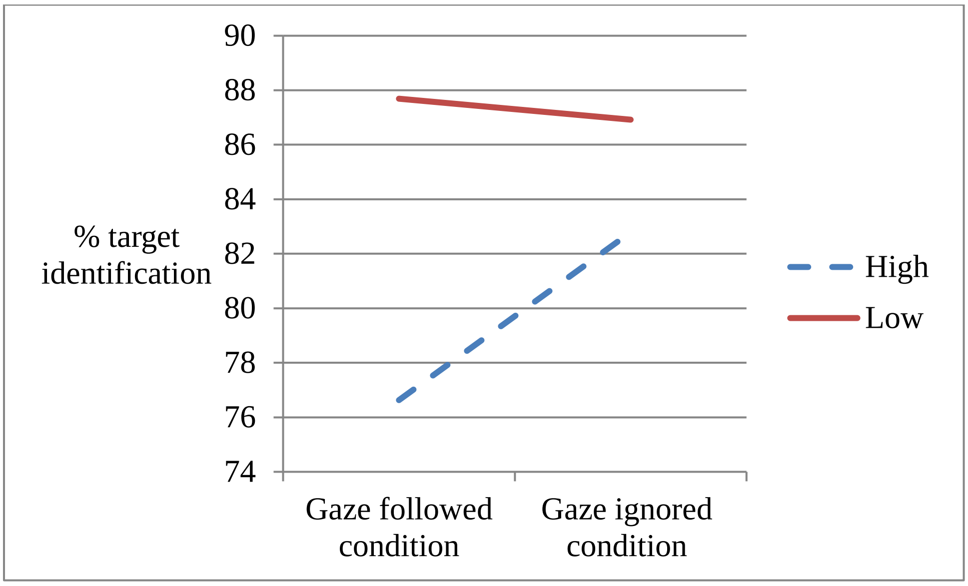

Figure 4.2. Interaction between JA condition and AQ group split on "imagination" factor, experiment 3.2

Overall, experiment 3.2 revealed no significant main effect of JA condition, image type or AQ group when the groups were split according to their overall AQ score. When the groups were split by their 'imagination' AQ scores, the high AQ group demonstrated significantly poorer image recognition than the low AQ group in the gaze followed condition and significantly poorer image recognition in the gaze followed than the gaze ignored condition.

4.4 Discussion

This study used the same joint attention tasks as experiments 2.1 and 2.2 to investigate RJA and IJA in typically developing adults with high and low levels of self reported autistic traits. In experiment 3.1, participants followed (RJA condition) and directed (IJA condition) an avatar's gaze to a placeholder to reveal a target image. In experiment 3.2, participants chose which placeholder to view to reveal the target image. The avatar subsequently followed or ignored their gaze shifts. Similarly to experiments 2.1 and 2.2, recognition memory for the target images was recorded and analysed. It was hypothesised that participants from the low AQ group would show enhanced recognition memory for target images in conditions where their gaze shifts were reciprocated by the avatar, simulating IJA (IJA and 'gaze-followed' conditions). Comparatively decreased recognition memory was anticipated in JA conditions where the participant followed the avatar's gaze to the target image (RJA condition) and where their gaze shifts were ignored by the avatar ('gaze-ignored' condition). This effect was expected to be considerably weaker or not detected in the group with higher reported autistic traits.

Contrary to the hypotheses, no difference in target image recognition memory was found between the RJA and IJA conditions for either AQ group in experiment 3.1. Similarly, in experiment 3.2, whether participants' gaze shifts were followed or ignored did not appear to have an effect on their overall recognition memory for the targets. This suggests that the type of JA between the avatar and participant did not affect participants' subsequent processing and encoding of the target image. The eye tracking data collected demonstrated that participants viewed the target images for a similar amount of time in the RJA and IJA conditions in experiment 3.1 and in the gaze-followed and gaze-ignored conditions in experiment 3.2. This shows that their allocation of overt visual attention to the target images was comparable between the JA conditions and suggests that they were likely to be similarly focused on the goal of the task (i.e. looking at and memorising the target image) during both tasks JA conditions. This means that viewing times to the target images is unlikely to explain the lack of enhanced recognition memory for the IJA conditions in the low AQ group. In study 2 of this thesis, child participants completing identical tasks consistently viewed the target images for less time in the IJA and gaze ignored conditions. Considered together, the eye tracking data from both studies suggests that the adult participants may have been more task-focused. The avatar and the presentation of the non-target image did not seem to affect their general viewing strategies for both of the tasks.

Overall, the findings of experiment 3.1 are in contrast to those of Kim and Mundy (2012) and Mundy et al. (2016) who found enhanced recognition memory for images encoded during IJA in typically developing adults and children. Another recent study following a similar procedure also found enhanced recognition memory under IJA compared to RJA conditions (Kim, Jang & Kim, 2015). Here, participants pointed or turned their heads to interact with the avatar. Participants' *d'* values were significantly greater and false alarm rates were significantly lower in the IJA condition when they pointed to the targets. False alarm rates were also significantly lower in the IJA condition when participants turned their heads towards the target images. The results of the current study are not consistent with these three previous findings. One major difference in methodology between these studies and the current study is the response of the avatar itself. In each of the past three studies comparing IJA and RJA, the avatar only made a gaze shift lasting 300ms. In the current study, the avatar conducts a head turn and a gaze shift, taking an additional 340ms. Further research is required to include variable stimuli presentations to determine if this effect is only evident when preceded by a quick gaze shift.

The results of experiment 3.2 also did not support the hypotheses and instead suggested that the avatar's reciprocity of the participant gaze shift did not affect recognition memory for the target. Again, the timing of the gaze shift and target presentation may have had an impact on this finding. Recently, Dodd et al. (2012) conducted a gaze cueing task where participants were asked to recall target words appearing either to the left or right of a schematic face. The face gazed towards (valid trials) or away from (invalid trials) the target location prior to target word presentation (the face was presented without pupils for 750ms, then pupils appeared gazing left or right for 500ms before target onset and remained fixated throughout the target presentation period). Here no effect of gaze direction on word recall was found when the target word was presented for 1000ms. When the target word was presented for 500ms and 250ms, the effect of gaze direction became significant. Specifically, the words presented incongruently to the gaze direction (invalid trials) were less likely to be remembered at these shorter presentation times than in the 1000ms condition. This suggests that the effect of an observed gaze shift on recognition memory may be reduced for target SOAs of 1 second or more. The authors argue that rather than this reflecting ‘enhancing’ effects of congruent gaze direction, the significant effect of gaze direction during the tasks with shorter SOAs is the result of a decrement in performance in the incongruent condition where attention being briefly drawn away from the target location has more of an impact. Interestingly, arrow cues had no effect on word recall at any SOA, suggesting this effect is gaze specific. Although this study did not use an interactive agent or IJA and is more directly comparable to classic gaze cueing paradigms, its findings may contribute to an explanation of the null results of the current experiment 3.2. The gaze cueing literature suggests that viewing a gaze shift can elicit a covert and reflexive shift of attention in the same direction (Driver et al., 1999; Frischen et al., 2007; Friesen & Kingstone, 1998; Langton & Bruce, 1999). In experiment 3.2, the avatar's non-reciprocal gaze shift in the gaze-ignored condition may indeed have drawn participants' covert attention away from the target image and the 1000ms target presentation may have been long enough to memorise targets equally effectively in both gaze followed and gaze ignored conditions. Whether a difference between these conditions may have been found in the current study if the images were presented for a shorter time should be further investigated. The inclusion of a condition where the avatar does not make a gaze shift away from the participants IJA gaze direction will also help unpick these findings. Importantly however, experiment 3.2 was an investigation of initiations of JA only, so the comparisons between these studies are made with caution. It also remains to be seen whether an image recognition task would elicit similar results as those found by Dodd et al. (2012) with word recall. Also, Kim and Mundy (2012) and Mundy et al., (2016) found that IJA enhanced recognition memory relative to RJA for images presented for one second. The differences between IJA and RJA are still not clear enough to unpick the reason for null results here. It is unclear whether these effects may be due to an enhancement of the referent or the effect of subsequently reducing 'noise' around the referent (Dosher & Lu, 2000). Future studies using the current paradigm manipulating stimuli SOA and gaze reciprocity will be helpful in delineating the effect of joint attention on recognition memory, under what circumstances IJA (reciprocated or otherwise) has an effect and how long lasting this effect may be.

Overall, when the participants were split into high and low AQ groups, their performance did not differ as a function of their reported autistic traits. Previous studies using this type of paradigm did not measure participants AQ scores so it is not known whether their participants had especially low, high or average levels of autistic traits. The current study had a good distribution of AQ scores for the high and low groups, with more extreme high and low scores than previous studies using the AQ for a similar purpose (e.g. Bayliss & Tipper, 2005; Bayliss, DiPellegrino & Tipper, 2005; Mckenna, Glass, Rajendran & Corley, 2015). It is unlikely that the significant difference between RJA and IJA found in the previous studies is due to participants with coincidentally low AQ scores.

When participants were split into high and low groups according to their scores on the ‘imagination’ AQ factor, a significant interaction between group and JA condition was found in experiment 3.2. Imagination is considered to be an important component of creativity and flexible thinking (Crespi, Leach, Dinsdale, Mokkonen & Hurd 2016) and is involved in the production and command of novel and spontaneous ideas (Vygotsky, 2004). Compared to other cognitive domains, literature focusing on imagination in ASD is sparse, especially in the adult population. Children with ASD have been shown to produce less novel ideas in imaginative drawing tasks (Craig, Baron-Cohen & Scott, 2000; Eycke & Muller, 2015 & 2016; Lewis & Boucher, 1991) and demonstrate reduced spontaneous pretend play in comparison to typically developing children (Jarrold, Boucher & Smith 1993; Lord & Rutter, 2013). The mechanisms underlying imagination have been suggested to include executive functioning (Carlson, Whyte & Taylor, 2013), local processing biases (Eycke & Muller, 2015), and social cognitive processes (Eycke & Muller, 2016). Indeed, autism is characterised by deficits in social interaction and communication, rigid and rule based behaviour and preferences for explicit and literal reasoning, rather than and impossible or illogical sequences of events that may require greater imagination (Craig & Baron-Cohen, 1999).

The imagination items in the AQ ask about how well the respondent can create an image of something in their mind, make up stories, imagine being someone else, imagine characters in a book and figure out their intentions. It also asks for respondents perceived enjoyment of pretend play and their preferences for factual information (e.g. preferences for reading non-fiction, visits to museums and collecting categorical information about things over theatre visits and fictional literature, Baron-Cohen et al., 2001). Higher AQ scores are indicative of greater levels of autistic traits, with higher scores on the imagination factor reflecting fewer imaginative traits. Here participants with higher AQ scores demonstrated significantly poorer target identification when their gaze was followed to the target images by the avatar, compared to when their gaze was ignored. Their performance in the ‘gaze-followed’ condition was also significantly poorer than that of the low AQ group. This suggests that the high AQ ‘imagination’ group may have had more difficulty memorising or recognising the target images when the avatar had followed their gaze to view them. It was expected that the low AQ group would demonstrate increased accuracy for target images when their gaze was followed and the high AQ group would show no difference between the two conditions. This was anticipated because the social relevance of initiated gaze being followed was anticipated to enhance encoding of the image for the low AQ group more than the high AQ group. Instead, the high AQ group’s performance seemed to decrease when their gaze was followed and the avatar’s gaze did not affect the low AQ group’s performance. Here, the low AQ group may be ignoring the avatar’s gaze completely as his gaze shifts were irrelevant to the task goals. The random nature of the avatar's behaviour may have led the high AQ group to find the avatar's gaze following more distracting or disconcerting than the low AQ group. Unlike in experiment 3.1, there was no seemingly consistent pattern to the avatar's responses in experiment 3.2. Even though participants were told that sometimes the avatar would follow their gaze and sometimes he would look at the opposite image, this pattern of responding could have been more difficult to interpret for those with high AQ scores on the imagination factor. It is more difficult to apply logical reasoning to randomised responses from both a rules based and a social perspective. The AQ imagination factor includes imagining the intentions and perspective of someone else. Ignoring a gaze shift is not in keeping with social norms and expectations of an interactive partner and the random response of the avatar may have made the stimuli more socially ambiguous for the high AQ group. This may therefore have been more difficult for those with higher AQ imagination scores to interpret or dismiss as task irrelevant and subsequently ignore. Furthermore, the added social load when the avatar did follow the participant's gaze may have weakened task performance for the high AQ group, rather than enhanced the low AQ groups performance as was expected. It should be noted here that the imagination subcomponent of the AQ includes aspects of creativity (e.g. "If I try to imagine something, I find it very easy to create a picture in my mind", "I find making up stories easy"), preferences for fact based interests (e.g. "when I was young, I used to enjoy playing games involving pretending with other children", "I don't particularly enjoy reading fiction") and social understanding (e.g. "When I'm reading a story I find it hard to work out the character's intentions", "I find it difficult to imagine what it would be like to be somebody else”). However, when participants were split into groups on the basis of their social skills score, communication score, attention to detail score and overall social interaction score (where subscales of imagination, social skills, communication and attention switching considered together), no differences in task performance were found. This suggests that the imagination and more creative component of interpreting social stimuli (e.g. imagining someone else’s intentions and imagining their perspective), rather than social preferences or expressed social behaviour may be important in the typical population during joint attention interactions. One other study has found a significant effect of imagination AQ score on performance of a task involving gaze cues. Lasalle and Itier (2015) found a weaker gaze cueing effect for adults with higher imagination AQ scores when viewing gaze cues from images of happy faces. The authors suggest that greater imagination may be needed to associate images of happy faces with real happy faces one would encounter in a real life social setting. Again suggesting the imaginative component of a social scenario is important for identifying differences in the typical population. The recent IJA study by Edwards et al. (2015) supports the suggestion that those high in autistic traits may be less efficient at responding to reciprocal gaze shifts of others. They found that unlike their low AQ group, the high AQ group did not detect targets appearing on faces that followed their gaze significantly faster than targets appearing on faces that looked the opposite way. It must be noted here that the group with high AQ scores for the imagination factor was considerably smaller than the low AQ group (N = 23 & N = 43 respectively) and these findings should be interpreted with caution. More research should be conducted with a larger sample of individuals with high scores on the AQ imagination factor.

In conclusion, the results of study 3 did not support the hypotheses. Overall, the type of JA between the avatar and participant did not affect participants' recognition memory for the target images. This contradicts previous findings of enhanced recognition memory performance under IJA. When participants were split into overall high and low AQ groups, no differences in task performance between the groups were found suggesting that levels of autistic traits, as measured by the AQ as a whole, did not impact participants' performance. When participants were split into groups according to their scores on the imagination AQ factor, those with high scores performed more poorly when their gaze shifts were followed rather than ignored. Further research comparing task performance with an avatar and a non-social, symbolic directional cue (e.g. an arrow) should be conducted to determine whether the social/intentional agent status of the avatar contributed to these findings. Further research using this paradigm should also be conducted to address methodological considerations such as SOA and target presentation time. A better idea of when RJA and IJA elicit differing effects on attention and memory will help better delineate joint attention in both typical and atypical development.

Chapter 5: General discussion

5.1 Aims of this thesis

This thesis aimed to investigate aspects of joint attention in Autism Spectrum Disorders (ASD) and the typically developing (TD) population. Research suggests that individuals with ASD show deficits in joint attention beginning early in childhood and persisting throughout the lifespan. These deficits are manifest in reduced eye contact and limited response to and initiation of joint attention with other people. The ability to efficiently and flexibly engage in joint attention with others is important for the development of theory of mind, language and communication skills. These skills contribute to social interaction, with which individuals with ASD struggle. As such, joint attention skills are considered pivotal in the developmental psychopathology and symptomatology of ASD and are of great interest to autism research. Successful joint attention is achieved using social cues such as eye gaze, gesture and vocalisations to establish common reference. It is hypothesised that reduced attention to this kind of social information (whether this be from atypical arousal, atypical attention mechanisms, atypical gaze following or reduced social motivation) may contribute to joint attention problems, leading to a reduction in the saliency, referential significance and understanding of social cues in ASD.

The eyes are the most prominent and communicative social cue, instrumental in joint attention interactions. Consequently, attention to and perception of eye gaze has garnered a great deal of research. Investigations into attentional and cognitive biases in complex, realistic and even dynamic scenes (e.g. Freeth et al., 2010;

Goldberg et al., 2008; Riby et al., 2013; Ristic et al., 2005; Swanson & Stiller, 2012 & 2013; Vlamings et al. 2005) suggest that individuals with ASD can and do follow eye gaze direction. Gaze cueing studies also suggest that gaze direction modulates spatial attention in children and adults with ASD and reflexive gaze following seems to be intact. However, considerable experimental evidence suggests that although individuals with ASD attend and respond to gaze and eye contact, they may do this atypically. Gaze does not seem to modulate attention, arousal and cognition in a typical way in individuals of all ages with ASD (e.g. Pellicano & McCrae, 2009; Riby et al., 2012; Senju et al., 2005; Senju & Johnson, 2009; Vlamings et al., 2005). Reports of subtle differences in responses to social and non-social cues between ASD and TD participant groups suggest that individuals with ASD may use non-social mechanisms for successful completion of these tasks. Recent studies have also suggested that attention to the referent, or gazed at object, is diminished in ASD compared to typical development (Fletcher-Watson et al., 2009; Freeth, et al., 2010; Riby et al., 2013). Furthermore, reports of individual differences in the typically developing population suggest that autistic traits may impact attention and responses to eye gaze (Bayliss et al., 2005; Edwards et al., 2015; Nummenmaa et al., 2012).

This research has focused overwhelmingly on investigating how people *respond* to joint attention (RJA) by way of gaze following and attention to an observed target or referent. Less in known about how we *initiate* joint attention (IJA). Consequently current research provides an incomplete picture of joint attention. This thesis aims to fill this gap in our knowledge and investigate eye gaze behaviour for both RJA and IJA and their subsequent effects on the processing of the referent object.

Three studies examined responses to gaze shifts, initiations of gaze shifts and associated cognitive processing of a target during computer-based tasks emulating gaze following and joint attention. The first study used a cueing task with pro and anti-saccade instructions to investigate both reflexive and voluntary cueing of overt visual attention. Here the relationship between gaze and arrow cueing and individual differences in autistic traits in TD adults was investigated. The final two studies used a gaze contingent avatar to investigate the effects of both following and initiating joint attention on recognition memory for the referent object. This was examined in children with ASD and TD child and adult participants groups. Throughout these studies, task performance of children with and without ASD and adults higher and lower in autistic traits were compared to investigate the effects of autistic characteristics.

The Autism Spectrum Quotient (AQ) was used to measure the autistic traits of typically developing adult participants. Participants were split into high and low AQ groups according to their self-reported levels of autistic traits. Individual differences in performance of certain behavioural tasks has previously been linked to autistic traits in the TD population (Bayliss & Tipper, 2005 & 2006; Brunye et al., 2012; Hudson et al., 2012). This evidence has contributed to the continuum approach to ASD, which suggests that certain 'autistic' cognitive and behavioural styles and personality traits may exist on a continuum extending beyond those with a formal diagnosis, to include the TD population. The AQ was used to detect any differences between groups with low and high levels of autistic traits and whether autistic traits affected responses to gaze cues and performance in joint attention tasks. This aimed to quantify patterns in task performance and cognitive and attentional biases that may be attributable to higher or lower levels of autistic traits. This hopes to provide a clearer picture of where on the autism continuum atypicalities in joint attention emerge and whether any differences in the effects of joint attention are associated with greater or fewer autistic characteristics. This could inform theoretical understanding about the mechanisms used for joint attention in ASD and typical development, whether these are similar and could be considered on a continuum or whether completely different and unique mechanisms may be implicated in joint attention deficits in ASD (Landry & Chouinard, 2016).

Throughout these studies, it was expected that adults with higher AQ scores and children with ASD would show different patterns of task performance than adults with lower AQ scores and typically developing children respectively. Furthermore, IJA was expected to enhance recognition memory of a target object compared to RJA and instances where IJA was not reciprocated. For adult participants, these expectations were not fully realised, the results suggest that performance of some joint attention behaviours may not be affected by autistic traits. Moreover, no significant differences between RJA and IJA were found. Comparison of children with and without ASD revealed differences in task performance in respect to JA viewing strategies and recognition of the referent. This discussion will address each study in turn before drawing overall conclusions and highlighting the strengths and limitations of this thesis. Suggestions for future research will also be considered.

5.2 Study 1

Experiment 1.1 and 1.2 of this thesis used pro and anti-saccade tasks to investigate reflexive and voluntary visual orienting towards and away from a target. The target was preceded by spatially uninformative gaze and arrow cues and saccadic reaction times (SRTs) and error rates were measured. Social-biological gaze cues were compared with non-social arrow cues to uncover any differences in how these are responded to by high and low AQ participant groups. Consistent with previous findings in the typically developing population, participants in the low AQ group were expected to show faster SRTs for arrow cues than gaze cues and to demonstrate lateralised congruency effects for gaze cues but not arrow cues (Vlamings et al. 2005). These differential gaze and arrow cueing effects were expected to be weaker for participants in the high AQ group and this group were expected to demonstrate lateralised congruency effects for arrow instead of gaze cues. This pattern of expected findings for the high AQ group is in line with the findings reported by Vlamings et al. (2005) for their high functioning ASD group.

In experiment 1.1 no differences were found between the groups with high and low autistic traits for either the pro or anti-saccade tasks. This suggests that visual orienting to social and non-social cues is not affected by autistic traits. For both tasks, the gaze cues elicited slower oculomotor responses than the arrow cues. This suggests that the gaze cues, as the more visually and qualitatively complex cue, may have required longer processing time for both groups. Interestingly, during the anti-saccade task, incongruent cues elicited more errors (here, errors were saccades towards the target) than congruent cues overall. This suggests that the participants adapted their saccadic responses for the anti-saccade task, preparing a response in the opposite direction of the presented cue. A main effect of cue suggested that incongruent gaze cues also elicited significantly more errors than incongruent arrow cues, suggesting that visual orienting to gaze cues may have been under less voluntary control than orienting to arrow cues during this task. One major limitation of experiment 1.1 was the removal of the fixation point before the presentation of the cue. Participants' eyes drifted considerably from the centre of the stimulus before they made their response, particularly during the gaze cue condition. This meant that the requirement for central fixation had to be relaxed.

In experiment 1.2 this limitation was overcome, the fixation point remained on the screen while the cue was shown, the SOA was reduced to 200ms and the non-directional, direct gaze cue was removed to more strictly control for central fixation before the saccadic response was made. Here, the anti-saccade task revealed no significant differences between the high and low AQ groups' performance and no differences in SRTs between the gaze and arrow cues. For the pro-saccade task, no overall group or cue type differences were found, however when the groups were considered separately this revealed subtle differences in responses between the groups. Although both groups SRTs suggested significant congruency effects for arrow cues, only the high AQ group showed a significant effect of congruency for gaze cues. Furthermore, this effect was only apparent for targets appearing on the left. Conversely, the low AQ group showed no effect of congruency. Interestingly, the lateralised congruency effect found in the high AQ group contrasts with the rightward lateralised congruency effect found in Vlamings et al.'s (2005) TD participants. Instead this is similar to the leftward congruency effect for gaze cues found in children with ASD (Stauder, Bosch & Nuij, 20122) and parents of children with ASD (Scheeren & Stauder, 2008) in replications of Vlamings et al.'s (2005) study. It must be noted here that unlike experiment 1.1 of this thesis and Vlamings et al. (2005), Scheeren & Stauder (2008) and Suader, Bosch and Nuij's (2011) studies that used an SOA of 400ms, experiment 1.2 used an SOA of 200ms and no non-directional cue preceded the directional cue. The parents of children with and without autism in Schereen and Stauder's (2008) study also did not differ in their AQ scores. Parallels between these studies are therefore drawn with caution.

For both the pro and anti-saccade tasks in experiment 1.2, arrow cue error rates demonstrated significant congruency effects whereas gaze cues did not. Higher error rates were found for incongruent arrow cues than congruent arrow and gaze cues and incongruent gaze cues. Unlike in experiment 1.1, this suggests that arrow cues may have been responded to more reflexively than gaze cues at this shorter SOA. One finding that was somewhat consistent across experiment 1.1 and 1.2 was that SRTs and error rates in the anti-saccade tasks (errors being saccades towards the targets) were greater for incongruent cues (although this difference for error rates did not reach significance for gaze cues in experiment 1.2). This finding that participants seem to prepare an anti-saccade in the opposite direction of the cue is therefore a robust one, supporting Koval, Thomas and Eveling (2005) and Wolohan & Crawford's (2012) suggestion that participants may adapt their 'response set' for the anti-saccade task. This demonstrates the flexible, task dependent and adaptive nature of visual attention to gaze cues and suggests that this can be controlled voluntarily, rather than simply reflexively. These results also underline the ambiguity around whether gaze cues are strictly endogenous or exogenous cues, they seem to be responded to both reflexively and voluntarily. As suggested by Frischen, Bayliss &

Tipper (2007), the categorisation of gaze cueing in terms of these labels may not be especially helpful, particularly if visual orienting is also affected by individual differences. Indeed, support for individual differences in gaze congruency effects were found in the pro-saccade task of experiment 1.2.

No congruency effect was found in the low AQ group in experiment 1.2 for pro-saccade gaze cues. This was a surprising result indicating that gaze direction did not affect low AQ participants' saccadic responses to the targets. This was unexpected because individuals with low levels of autistic traits are expected to be more sensitive to the social meaning of gaze. This effect only occurred with the shorter SOA and the removal of the non-directional cues. The removal of the non-directional cue may have reduced the direct, personal relevance of this cue for the low AQ group. Alternatively, not all cueing studies have found validity effects (Frischen et al., 2007), for example, Bayliss & Tipper (2005), Heitanen et al. (2006) and Schereen & Stauder (2008), did not find effects of congruency in all of their participants. This suggests that individual differences in the validity effect more generally may exist in the typical population. Experiment 1.2 suggests that individuals low in autistic traits may not demonstrate validity effects when gaze cues are presented at very short SOAs. Because there is no standard procedure for the gaze cueing paradigm it is not clear what exactly may cause this. Various stimuli, SOAs and response instructions make interpretation and comparison to previous studies difficult. More research will be required to systematically investigate what specific individual differences and cueing circumstances may cause differences in gaze cueing in the TD population with varying levels of autistic traits. ASD itself is very heterogeneous and the expression of behaviours in the autism continuum in the typically developing population itself may be too.

One of the main strengths of the studies in Chapter 1 was the novel use of eye tracking and pro and anti-saccade task instructions combined with a gaze cueing task. This is unique to this participant sample and is the first cueing task to tap inhibitory oculomotor responses in an attempt to reveal gaze cueing differences along the broader autism continuum. Although the results here do not provide clear answers, they suggest that oculomotor responses may be a promising way to investigate gaze cueing in future studies.

The main limitation of the studies in Chapter 1 and indeed of gaze cueing studies more generally is perhaps the impoverished display and arbitrary target used. Context dependent effects of the target object and the central face were not manipulated here. Previously, responses to fearful (Miu, Pana & Avram, 2012) and happy faces (Lasalle & Itier, 2012), and faces with learned friendly and unfriendly dispositions (Hudson, Njiboer and Jellema, 2012) have elicited different gaze cueing effects in participant groups with higher and lower AQ scores. Previous studies have also found that differences in cueing effects between these groups may be dependent on the content of the target. For example, Bayliss and Tipper (2005) found that those with more autistic traits were more efficiently cued to scrambled images than intact images and more weakly cued to face images than their low AQ counterparts. More recently Zhao, Uono, Yoshimura and Toichi (2015) investigated cross modal gaze cueing with gaze cues and auditory targets. These targets were either voice or tone sounds played to the left or right ear. Interestingly they found no significant differences between low and high AQ groups' cueing effects at a small SOA of

200ms (similar to the SOA in experiment 1.2 of this thesis) where gaze cues facilitated faster detection of social (voice) than non-social (tone) targets for both groups. However, at a longer SOA (800ms), the low AQ group showed differential cueing effects for social and non-social targets, demonstrating validity effects for the tone target and inhibition of return for the voice target. This difference was not found in the high AQ group who showed no cueing effects for either cue at the longer SOA. This suggests more fleeting cueing effects and weaker contextual modulation (social/non-social target) for cross modal cueing in individuals with high AQ scores. This finding is at odds with the findings of experiment 1.2 where of a lack of congruency effect for the low AQ group was found at the short 200ms SOA, however, Zhao et al., (2015) presented a direct gaze cue before the directional cue. The comparatively attenuated effect found by Zhao et al. (2015) suggests that the enhanced object processing found in multimodal joint attention interactions may be weaker and more transitory for those with higher levels of autistic traits. It will therefore be interesting to adjust the social modalities and content of the cue and the target object as well as the SOA in future cueing studies. In the current thesis, context dependent effects were found in whether the task required a pro or anti-saccadic response, so other task and context dependent effects should also be explored. Another limitation of gaze cueing paradigms is that they inform us only about the responses of the observer of a gaze shift. This omits the initiator and does not provide much detail on how deeply the referent is processed in a triadic joint attention scenario. As such, the studies in chapter 2 and 3 of this thesis were designed to examine the effects of both RJA and IJA on the processing of the referent object.

5.3 Study 2 & 3

Chapters 3 and 4 of this thesis addressed aspects of joint attention that are currently under researched in experimental investigations. Due to methodological barriers, work on joint attention has mainly focused on RJA, rather than IJA. Little is also known about the effect of joint attention on the encoding and processing of the referent object. Advances in gaze contingent eye tracking methodology have allowed RJA and IJA to begin to be explored in the context of overt visual attention and gaze behaviour. Initial work suggests that IJA may have a greater effect on the processing of the gazed at referent than RJA or where IJA is not reciprocated (Edwards et al, 2015; Kim & Mundy, 2012; Mundy et al. 2016). Studies also suggest that IJA enhances encoding and subsequent recognition memory for referent images compared to RJA (Kim & Mundy, 2012; Kim et al., 2015; Mundy et al. 2016).

Studies 2 and 3 aimed to explore this further and engage participants as responders and initiators of joint attention. For these studies, children with ASD, TD children matched on age and IQ and TD adults with high and low AQ scores coordinated their gaze shifts with a virtual agent to a series of images they were asked to memorise. In task 1, participants followed (RJA) and directed (IJA) the avatar's gaze to the images. In task 2, the avatar's reciprocity to participants' gaze shifts was manipulated and participants' gaze shifts to the placeholders were either followed by the avatar (gaze-followed, IJA) or ignored (gaze-ignored, no IJA). It was hypothesised that typically developing children and adults with low levels of autistic traits would benefit the most from being the object of the avatar's attention and show enhanced recognition memory for target images in IJA conditions. Children with ASD and adults higher in autistic traits were not expected to show this benefit for the

IJA condition as strongly and were instead expected to show similar recognition memory in the RJA and IJA conditions.

These hypotheses were not fully supported for either the child or adult participant groups. For participants who performed the tasks at above chance level, whether they followed or directed the avatars gaze and whether or not their gaze shifts were reciprocated did not have an effect on their recognition memory for the referent images. This does not support early findings of enhanced recognition memory in IJA conditions in typically developing adults and children (Kim & Mundy, 2012; Kim et al., 2015, Mundy et al., 2016). Instead, this thesis suggests that RJA and IJA may have comparable effects on information encoding and processing, at least in the context of the experimental paradigm used here.

Here we looked to the gaze data to contribute to an explanation for these results. This allowed examination of visual attention allocation during encoding of the target images. Viewing times to the target image, non-target image and avatar, during the show target period were analysed. This revealed very different task viewing strategies for the adult and child participants and between the ASD and TD child groups. The adult participants appeared to be very task focused and demonstrated consistent and comparable viewing times to the target images across task and condition types. This suggests that how their attention was coordinated with the avatar to the target image did not affect the subsequent amount of visual attention it was allocated, or its depth of encoding.

Conversely, the child participants demonstrated a much broader allocation of attention during the target processing time period. Both the ASD and TD groups attended to the avatar and the non-target image during the show target period when they were asked to memorise the target. This is demonstrative of a less optimal viewing strategy than adults for successful completion of the task. Interestingly, in experiment 2.1, comparisons of JA conditions showed that both the ASD and TD children looked for significantly longer at the non-target image and the avatar and significantly less at the target in the IJA condition when compared to the RJA condition. This did not appear to affect their recognition memory for the images between these conditions. This may suggest a lower threshold of time required for processing of the referent object in the IJA condition. More research will be required to investigate what the parameters of this threshold may be. Experiment 2.2 also revealed interesting differences in attention allocation to the task between the ASD and TD groups. Unlike in experiment 2.1, the avatar's gaze direction did not affect TD participants' attention allocation to the target image in experiment 2.2. The ASD group however, looked more at the non-target image when their gaze to the target was ignored and the avatar viewed the non-target image. This suggests that the non-target image was more captivating to the ASD group when avatar looked at it. Unlike experiment 2.1, the contingency of the avatar's gaze shift in experiment 2.2 was irrelevant to the target to be memorised. The TD group seemed to adapt their viewing strategy for this task where the ASD children did not. It must be noted that a different pattern of findings for experiment 2.2 emerged when participants who performed at below chance level were included in the analysis. Here a significant effect of JA condition was found whereby target recognition was enhanced for both groups when the avatar followed their gaze shifts (gaze-followed condition) compared to when he ignored their gaze shifts (gaze-ignored condition). However, this finding is tempered by the accompanying finding of similar responses to non-target images in the gaze-ignored condition. Non-target images were not intended for memorising and evidence of increased viewing of the non-target images and the avatar in this condition suggests that attention allocation towards these AOIs may have contributed to unsatisfactory task performance in participants who performed below chance.

Viewing times to the avatar can provide hints about how the reciprocity of his gaze shifts may have been interpreted by participants. These were only analysed in the child participant groups as the adult group showed limited viewing of the avatar during the analysed task period. Interestingly, both ASD and TD child groups (including those performing below chance) demonstrated greater looking times to the avatar in the IJA condition in experiment 2.1 and when he ignored their gaze shifts in experiment 2.2. This could be interpreted as the children monitoring the avatar's gaze behaviour in response to their own. Increased viewing to the avatar in the IJA condition suggests that the participants were checking that he has followed their gaze shift (Carpenter & Liebal, 2013) and increased viewing when he ignored the participants' gaze shifts may indicate difficulty in interpreting a gaze shift that is contrary to participants' expectations and the social norms of gaze following (Bayliss & Tipper, 2013; Swanson & Siller, 2012, 2013; Pelphrey et al., 2003 & 2005).

One consistent finding of study 2 was of poorer recognition memory in the ASD group than the TD group. Several previous studies have demonstrated comparable recognition memory for non-social images in children with and without ASD (Boucher & Lewis, 1992, McPartland et al., 2011; Snow et al., 2011; Weigelt, Koldewyn & Kanwisher, 2013). Deficits in image recognition in ASD have also reported to be specific to face or social images (Boucher & Lewis, 1992, McPartland et al., 2011; Snow et al., 2011; Weigelt, Koldewyn & Kanwisher, 2013). However, one study has found impairments for both face and non-social stimuli recognition (Ewing, Pellicano & Rhodes, 2013). More domain general recognition memory deficits have also been suggested as part of the cognitive profile of lower functioning children with ASD (Bigham et al., 2010; Joseph, 2005). It is plausible that the current findings could reflect an overall weakness for image recognition memory in the children with ASD compared to TD children. However, the groups were carefully matched on age and full scale IQ and did not significantly differ in performance on a visuospatial working memory task. This study was also not designed to investigate recognition memory in itself or determine differences in encoding, recollection or familiarity of the target images. It has been suggested that recollection but not familiarity may be impaired in high functioning individuals with ASD whereas both may be impaired in lower functioning ASD populations (Bigham et al., 2010; Joseph et al., 2005). Future studies may benefit from adapting the style of memory task here. For example, understanding whether participants are using recollection or a feeling of familiarity to complete the task could be investigated by using a "remember/know" paradigm (Tulving, 1985). Alternatively, the task could be adapted to investigate incidental memory of the images without explicit instructions to pay attention to the gaze shift and remember the referent images only.

Instead, viewing times to target images may better explain the ASD group's poorer performance. Overall, ASD participants distributed their viewing across the screen and focused significantly less on the target images than the TD children. This supports recent findings of ASD participants spending less time viewing referent images than TD controls (Fletcher-Watson et al., 2009; Freeth et al., 2010; Riby et al., 2013). This means they had comparatively less time to encode the target images, this appeared to affect their recognition performance. It is not yet clear what could be driving these differences in viewing strategies but there are a variety of possibilities. For example, reduced referential significant of the referent object, more difficulty in interpreting the avatar's actions, atypical modulation from the avatars gaze, poorer concentration and weaker attentional strategies for the task, or increased distraction to the other AOIs could all have impacted the individuals in the ASD group in different ways. Alternatively the demands of the task may have been too high for some of the children. It is possible that the extra cognitive load of monitoring the gaze of the avatar and choosing a placeholder to view the target images may have made the current task all the more difficult for the some of the children from both the ASD and TD groups.

Overall, the memory task data and the complimentary eye gaze data gleaned from studies 2 and 3 of this thesis are very informative in raising further research questions and highlighting necessary improvements on this and existing gaze contingent experimental paradigms. The null effects of JA condition found here do not support previous findings suggesting that IJA is beneficial for the encoding, processing and organisation of information. RJA and IJA have distinct early developmental trajectories and may elicit separate but overlapping neural mechanisms (Mundy et al., 2012; Mundy & Newell, 2007; Schilbach et al., 2010). Indeed, the findings that IJA comparatively enhances recognition memory (Kim & Mundy, 2012; Kim et al., 2015; Mundy et al., 2012) suggest that these distinct RJA and IJA mechanisms may affect stimuli processing and encoding in different ways. Kim and Mundy (2012) speculate that the differences they found may reflect differences in self vs. other processing. IJA may elicit more self-referenced, self-motivated and voluntary attentional mechanisms and RJA may incur more other-referenced spatial attention, which could be more reflexive. Mundy et al., (2016) further suggest that your own actions being under the attentional focus of another may boost activation in social and attentional neural networks. This idea is supported by theories suggesting that eye contact elicits widespread activation in the social brain and findings that direct gaze enhances performance in a range of face and gaze processing tasks in typical development (e.g. Hood et al., 2003; Macrae et al., 2002; Senju & Johnson, 2009). Kim and Mundy (2012) and Mundy et al.'s (2016) finding suggests that IJA may enhance subsequent information processing and encoding more than RJA. If this is the case in typical development but not in ASD, individuals with ASD could be at a particular disadvantage when using IJA for learning. The studies in the current thesis however found no differences in stimuli processing between RJA and IJA conditions, instead suggesting that RJA and IJA have similar effects and JA may more generally affect information processing in a consistent way.

There are however important methodological differences between the current and previous gaze contingent studies (specifically, Kim & Mundy, 2012; Kim, Jang & Kim 2015 & Mundy et al., 2016). Perhaps most importantly, the addition of a head turn in the current investigation meant that the timing between the beginning of avatar's attention shift and the presentation of the target was longer in the current study than previous studies. The literature on visual orienting and gaze cueing suggests that the timing of stimuli presentation is likely to be crucial to understanding the reflexive and voluntary attention processes underlying both RJA and IJA and their subsequent effects on target object processing. It is known that observing a gaze shift rapidly facilitates an attentional shift, which peaks at around 300ms and is sustained for up to 1000ms when the facilitative effect diminishes completely (Driver et al., 1999; Frischen & Tipper, 2004). Furthermore longer SOAs of 2400ms have elicited inhibition effects for gaze cues (Frischen & Tipper, 2004). These reflexive and voluntary processes and facilitation and inhibition effects incurred upon viewing a gaze shift are thought to occur in parallel and interact (Hill et al., 2010, Frischen & Tipper, 2004). Frischen and Tipper (2004) proposed that the facilitative and inhibitory effects elicited by gaze could cancel each other out at intermediate SOAs of around 1200ms. It is plausible that similar mechanisms with temporal aspects that are currently unknown may affect IJA when perceiving a reciprocal gaze shift. Systematically varying SOAs for gaze and target presentation times in future JA paradigms will help to unpick the effects of both reflexive and voluntary social orienting on subsequent object processing (Hill et al., 2010) for RJA and IJA. The short-lived reflexive influence of gaze cues on spatial attention may transfer to effects of IJA on subsequent object processing. The 'enhancement' effect of a reciprocal gaze shift in IJA found by Kim and Mundy (2012) and the lack of difference found in the current thesis suggest that this effect may be constrained by the narrower contingencies used in Kim and Mundy's (2012) study in comparison to studies 2 and 3 of the current thesis. The effects of joint attention on recognition memory may therefore be short lived (Dodd et al., 2012). Alternatively, if differences between groups with and without ASD and high autistic traits are found at longer SOAs, more spontaneous, voluntary and sustained attention to the target object may be contributing to JA atypicalities in ASD. Determining the timing of the stimuli presentation which elicits significant effects of JA and memory will be informative about which mechanisms are used for this task, how early this effect occurs and how long it is sustained for.

Furthermore, the timing of reciprocal gaze shifts in IJA conditions during this paradigm is likely to be crucial to unpicking any meaningful effects. Pfeiffer et al., (2012) suggest that if the delay between the participant and avatar's gaze shift is too short or long the avatar's response may seem coincidental or unrelated rather than reciprocal. This effect also seems to be mediated by the participants understanding of the avatar's sense of agency and whether or not the avatar can look elsewhere (Pfeiffer et al., 2012). Future studies should methodically examine the temporal components of each element of JA interaction from start to end to fully explore these possibilities. Alternatively, the addition of a gaze shift and head turn here may have increased the saliency of the avatar to such an extent that it distracted too much from the target image and reduced any target memory enhancing effects.

Furthermore, the choice of the referent object is an uninformed one. Participants chose a blank placeholder and when they and the avatar coordinated their attention to it the image appeared. IJA could further enhance processing if participants are able to make an informed choice about the referent object, based on their own preferences. For example, Bayliss and Tipper (2013) found increased affective evaluations of chosen objects and faces that gazed towards one of two objects when viewed by the participant compared to the faces that did not reciprocate the participants' gaze shifts and gaze shifts towards objects that were not reciprocated. Separating the effects of object preference alone and IJA in this scenario will be a difficult but worthwhile task for future research. It is also not yet clear what effect the pattern and timing of stimuli presentation has on the results of the available studies. It would be of interest to present the referent both before and after the social partners' gaze shift response to disentangle this. With continued use, incremental and systematic changes in SOA and presentation, the gaze contingent JA paradigm could begin to delineate gaze initiations with the same success as gaze cueing paradigms in delineating the time course and robustness of the effects of gaze cueing.

Future research should also assess the suitability of these paradigms to study social cognition, examining to what extent they elicit social cognition will be important (Kim & Mundy, 2012; Mundy et al., 2016). As highlighted by Carpenter and colleagues (e.g. 2011; 2012), the idea of "knowing together" is also important for joint attention. In IJA, showing another person an object is often to share interest alone. This aspect of IJA is potentially the most rewarding (at least for TD populations). The current study was not designed or able to tap into this and was only able to approximate a social interaction with the avatar. The null findings here may indicate that our virtual character was perceived as less socially engaging or responsive than the one used by Mundy and colleagues. Although "Danny's" social saliency was presumed to be high and many previous studies have used avatars to investigate socio-cognitive effects, the participants' perceptions of the avatar were not measured here. Efforts were however made to enhance the social presence of the avatar. A welcome screen and the explicit instruction that participants would be looking at images along with the character as a memory game were included. This was novel to the RJA/IJA paradigm and in keeping with the introduction of the character in the Echoes program (Bernardini, Porayska-Pomsta, & Smith, 2014). Furthermore, the novel addition of a "sharing look" after the target image had been presented aimed to further enhance the participant's interaction with the avatar. To further investigate the "social" effect of the avatar and align with the gaze cueing literature, future studies comparing IJA and RJA should also compare social interactive agents with a symbolic non-social equivalent such as an arrow. This will be informative about effects that may be specific to social reciprocity rather than lower level effects.

Future studies should also utilise gaze data collected throughout the whole JA interaction to obtain a more fine-grained analysis of participant's gaze behaviour with the avatar. For example, saccadic latencies for gaze following, latencies for and the frequency of 'check back looks' towards the avatar and returns to the target will be informative for delineating exactly how individuals engage in joint attention episodes with virtual humans. Fuller data on these gaze contingent paradigms will ultimately be very helpful for the development of socially assistive technology for individuals with autism and for the development of more sophisticated joint attention experimental paradigms. Findings from the current study already provide several suggestions for how interactive characters can be optimised to better suit the needs of individuals with ASD during joint attention interactions.

Here, the structure of the interaction was clear and the avatar was reliable and predictable, the task also had explicit goals. These are all elements that are important in virtual environments for children with ASD (Frauberger, Good, Alcorn & Pain, 2013). However, the current findings suggest that individuals with ASD may need more time and perhaps additional cues to interpret gaze, focus on and process the referent object. Their more scattered attention may benefit from enhancing the saliency of the referent object. For example, a recent gaze contingent paradigm investigating the use of referential gaze for novel word learning presented high functioning children with ASD and TD controls a schematic face that gazed at and vocally labelled one of two simultaneously presented novel objects (Akechi et al., 2011). The face either labelled the object that the participant happened to fixate (follow on condition) or the opposite object not fixated by the participant (discrepant condition). In the follow on condition, both groups looked more at the target object than the non-target object and were later able to identify the novel object successfully. However, in the discrepant condition the ASD group looked equally at the target and non-target objects, whereas the TD children looked for significantly longer at the target object and were more able to successfully label the novel objects than the ASD group. In a further experiment when the salience of the target object was increased, by making it bounce slightly, visual attention and subsequent naming of the target object was equivalent for both groups (Akechi et al., 2011). In the current study, the non-target images drew a lot of attention from the ASD group in particular, removal of this distractor for future studies may elicit different findings and help focus the task goal (Georgescu et al., 2014). It is important to note that in real life face-to-face joint attention interactions several environmental distractors will likely be present. Additional prompts such as auditory or visual supports may also help scaffold the interaction with the character. Future studies could also make the interaction with the character more personal. For example the use of the child's name or customising the referent objects to reflect personal interests may enhance interactions with the character (Alcorn et al., 2011; Frauberger et al., 2013). Despite these drawbacks, the current study has demonstrated that children with ASD (slightly lower functioning than the participants of Mundy et al., 2016) can engage in interactive gaze contingent environments and the above suggestions gleaned from the results may improve these environments in the future. These results may also inform and encourage future computer based interventions and studies to use gaze contingent virtual avatars. A gaze contingent character similar to “Danny” could be a low cost way for children with ASD to practice joint attention in a predictable and non-threatening environment. It also has the potential to be programmed into customisable virtual environments with an endless possibility of referent objects.

5.4 Theoretical and practical implications

Overall, the findings of this thesis have implications for joint attention theory and attempts to explain joint attention deficits in ASD. The findings also have implications for the continuum view of ASD, specifically in relation to joint attention. Joint attention theory suggests that RJA and IJA have different developmental trajectories and separate but overlapping mechanisms (Mundy & Newell, 2007). This is supported by evidence from infants and very young children (Brooks & Meltzoff, 2008; Mundy & Neal, 2001). Emerging evidence from older children (Mundy et al., 2016) and adults (Kim & Mundy 2012) suggests that RJA and IJA may also affect information processing differently. The findings from this thesis do not support these assertions and instead suggest RJA and IJA may have similar effects on processing of the referent object. This suggests that in later childhood and adulthood the mechanisms for RJA and IJA may not always differently affect subsequent processing of the referent. Whether this changes from toddlerhood through childhood to adulthood remains to be seen and longitudinal studies would bring more clarity to the developmental trajectory of the attention processes involved. Given that the current study used a paradigm with longer SOAs than previous studies, this could mean that any differences the effect of JA has on information processing may only occur for more rapidly presented stimuli. Although it is theorised that IJA uses more voluntary, anterior attention processes, the impact of faster more posterior attention mechanisms, usually associated with RJA, and the automatic processing incurred when stimuli is presented quickly should be considered. For slower, more voluntary processes, behavioural differences in RJA and IJA might not emerge.

The pattern of results for participants performing above chance at the tasks in study 2 and 3 was similar for children with and without ASD and for adults with higher and lower levels of autistic traits. Children with ASD however performed more poorly at the JA tasks. One striking finding was the different allocation of visual attention between ASD and TD groups. The ASD group demonstrated a less task-oriented strategy, instead viewing the avatar for longer and looking more at task irrelevant parts of the screen. This supports theories suggesting atypical allocation of visual attention in ASD and suggests that atypical attentional biases may contribute to JA problems in ASD. Indeed, researchers are beginning to suggest that theories about visual attention should be framed in terms of how individuals view their environment rather than 'how well' (Burack et al., 2016). The current findings improve our understanding about how individuals with ASD attend during JA scenarios and these may have important practical ramifications. For example, differences between RJA and IJA in ASD could direct the focus of JA interventions for children with autism. It is presumed that deficits in IJA are more pronounced than RJA, yet the current findings would suggest that this is not the case.

Similarly, there were no differences between RJA and IJA in TD adults with higher and lower overall levels of autistic traits. This does not support the continuum view and suggests that the effect of JA on attention towards and recognition of a referent is not affected by overall autistic traits. This suggests that difficulties with JA may be specific to individuals (or a subgroup of individuals) with ASD and not detectable along the broader autism continuum. However, when the imagination subcomponent of the AQ was isolated, high scoring individuals performed more poorly at experiment 2.2 when their gaze shifts were reciprocated. The imagination factor includes imagining being someone else, imagining a character in a book and figuring out their intentions. The imaginative component of a social scenario may therefore be an important factor for successful JA interactions in the typical population. Another subtle difference between the high and low AQ groups was found in experiment 1.2 where participants with high levels of autistic traits showed a unique laterality bias for prosaccades towards rapidly presented gaze cues This suggests subtle differences in visual orienting to gaze on the broader autism continuum. This task tapped into faster, more automatic attention processes to elicit these differences, further suggesting that the impact of autistic characteristics on JA may lie in more reflexive and automatic processes.

5.5 Strengths and limitations

The major strength of this thesis was the novel methods used throughout the studies reported, specifically, the use of eye tracking and gaze contingent methods. This allowed for good experimental control and more ecological eye movement responses to be recorded. In the first chapter, a gaze cueing paradigm measuring overt visual attention combined with a pro and anti-saccade task was novel for this participant group. The use of a gaze contingent avatar was also novel and a step in the right direction for studying the intricacies of both RJA *and* IJA. An understanding of both of these components of joint attention will be important for a fuller understanding of joint attention mechanisms for both typically developing and autistic individuals.

The participant samples in this thesis were also good in terms of sample size and group matching. The child participant samples in study 2 were very carefully and individually matched on age and general intellectual ability. This strategy of individually matching the participants resulted in good group comparisons despite some participants being removed from the analyses. In studies 1 and 3 the spread of AQ scores was also similar to those reported in previous studies (e.g. Bayliss & Tipper, 2005; Lasalle & Itier, 2010; Miu, Avran & Pana, 2012). Although the strategy in study 3 of selectively recruiting participants on the basis of their extreme higher or lower scores would be recommended for future studies, this elicited a better range of high and low scores than the median split method which was used in study 1. Future studies should also attempt to recruit participants with extreme scores on specific AQ factors. This may help identify individual differences within subgroups of the AQ which may be more useful than investigating the AQ as a whole.

A limitation of this study is the computer-based nature of the investigation because only an approximation of a joint attention interaction can be achieved. Real life, face-to-face joint attention interactions may elicit different findings than lab-based measurements (e.g. Gallup, Chong & Couzin, 2012; Laidlaw, Foulsham, Khun & Kingstone, 2011; Macdonald & Tatler, 2013). Indeed, all experimental studies of social processes must tread this line between ecological validity and experimental control. Here we believe that study 2 and 3 improved on the ecological validity of past experimental studies of JA. The participant interacted with the avatar and their eye movements had a consequence on the avatar's behaviour, making them an active participant in the task. This is more representative of the reciprocal nature of real life interactions. However, it must be noted that the social presence of the character was not measured, nor was the participants' perceptions of having their gaze followed by the avatar. Future research should investigate the extent to which participants experienced the avatar's behaviour as being contingent on their own gaze shifts (Pfeifer et al., 2012). Individuals' personalities (von der Putten et al., 2010), their expectations of how virtual agents will respond and their previous experience with them can effect perceptions of these interactions (Garau, 2003). Participants in the current study were explicitly told that their eye movements would be tracked so that the avatar could respond to them. Nevertheless, technical expectations around the avatar's responses may have differed between participants. If the avatar's gaze shifts were not as responsive as expected or perceived as too 'machine-like', this may have affected perceptions of the character's contingency and agency. Indeed, future studies should evaluate the perceived quality of the interaction.

With advancements in technology the methodological challenges of studying joint attention are likely to be overcome with increasingly immersive environments and more responsive virtual agents. However, the balance of ecological validity and experimental control will remain a significant challenge for this kind of research. Increasing the ecological validity and the sophistication of avatar-human interactions may require increasingly complex stimuli and tasks. Technology will likely move faster than our knowledge about socio-cognitive mechanisms active during interactions with increasingly lifelike virtual stimuli. This will make interpreting findings a challenging that will require extensive research by experts from disciplines across developmental and cognitive psychology and computer sciences (Georgescu et al. 2014).

5.6 Overall conclusions

Overall, the current thesis used novel methods to investigate different components of joint attention. The most significant contribution to knowledge here is the innovative use of a gaze contingent virtual avatar to investigate both responding to and initiating joint attention and how these affect subsequent processing of the referent object. This thesis proposed a portable, one system, and computer-based method for incorporating IJA into simulated joint attention interactions. This is an important step in overcoming the methodological barriers that constrain the experimental study of both RJA and IJA. As such, this thesis provides some important lessons for the future study of joint attention with children and adults from typical and clinical populations.

Here we found no significant differences between RJA and IJA on recognition memory for the referent object in either an adult or child populations. This also did not vary with levels of self-reported autistic traits in adults or ASD diagnosis in school aged children. This suggests that the mechanisms behind both RJA and IJA appear to have similar effects during a simulated joint attention interaction with a computer character in both ASD and TD. This does not support early work demonstrating enhancement effect of IJA in typical development, nor theories such as the parallel distributed processing theory which suggests that IJA, involving more self-referenced processing and more reward based mechanisms, may lead to enhanced organisation, processing and encoding of information. However, it must be noted that these studies of IJA are in their infancy and any links to joint attention theory are tentative and speculative at this stage. The current thesis consequently generates more questions about IJA and how to study it than it can answer. Future research should continue to use eye-tracking data to analyse how this paradigm is responded to and further improve methodological and attentional control for improved clarity on IJA mechanisms.

This thesis also investigated autistic traits in the general population. It further supports the idea that subtle individual differences in autistic traits may affect attention to gaze direction cues at very short SOAs. However, the processing of a referent object does not seem to differ as a function of autistic traits except perhaps in those with high AQ scores on the imagination factor.

It is clear from these studies that a comprehensive characterisation of cognitive and behavioural performance during these tasks and how this relates to autism and autistic traits is required to make connections between JA mechanisms and the broader autism continuum. Refining and optimising this methodology will therefore be important for future research. The more subtle elements and dynamic nature of social interactions is likely to be difficult for those with ASD, so further investigations and incremental adjustments of the social content and stimuli presentation will be a fruitful avenue for future research.

In conclusion, experimental studies comparing IJA and RJA are still at an early stage. This thesis therefore raises more questions about differences or lack thereof of IJA and RJA and their effects on social information processing. This thesis does however offer much in the way of informing future studies' methodology. This study used very novel methods with established software as an initial step into investigating joint attention in a more interactive and procedurally sophisticated way. This series of studies has therefore overcome some of the previous methodological barriers for experimental research on joint attention. In particular it has demonstrated that school aged children with ASD can use gaze contingent applications to take part in these kinds of interactive experimental paradigms. Importantly, this thesis also highlights key considerations that should be addressed in future to make these kinds of paradigms as robust and informative as possible. Addressing these limitations in future research will help create experimental paradigms that could prove as useful in our understanding of RJA and IJA as the gaze cueing paradigm has been in our understanding of reflexive visual attention to gaze cues.

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