Social attention biases in adults with and without Autism Spectrum Disorders: Selecting and following eye-gaze and arrow cues in real-world scenes

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Abstract

[Background] Despite obvious impairments in following another person's eye-gaze during social interactions, individuals with Autism Spectrum Disorders (ASD) show typical gaze-following on standard attention tasks. Most attention tasks do not differentiate gaze-selection (focusing on someone's eyes) and gaze-following (following another person's gaze) components of social attention and may not be sensitive to ASD differences. **[Aims]** The goal of this study was to first effectively characterize attention orienting during gaze-following in adults with typical development (TD) and then explore any relative differences in individuals with ASD. Participants were allowed to <u>select</u> cues in a manner that revealed their priorities. In particular, biases for eye-gaze vs. arrow cues were compared using a flicker task to present real-world scenes. **[Results]** In Experiment 1 when participants were shown either eyes or an arrow, TD adults demonstrated no preference for gaze-following over arrow-following, suggesting that single cues do not reveal biases. In Experiment 2 TD participants viewed competing eyes and arrows and showed an initial preference for gaze-following. As the task progressed, gaze-following diminished, suggesting that the behavior may be susceptible to conscious influence. Experiment 3 involved a forced choice response after variable durations of viewing the scene (i.e. short, medium, long) in order to examine the time course of gaze-following. Eyes were selected at short viewing durations, followed at medium durations, and re-selected at long durations. A different pattern was found for arrows, suggesting that they are attended differently. In Experiment 4, the visual saliency of arrows was reduced and arrows were no longer followed; arrow following may rely upon visual saliency, whereas gaze-following likely relies upon social saliency. In Experiment 5, gaze-following was examined in adolescents and young adults with and without ASD. Performance of participants with ASD differed from comparisons in two ways, they: 1. showed no preference to select eyes over arrows and, 2. did not follow eye-gaze. **[Conclusion]** Findings suggest that TD adults prioritize eyes and then have a flexible bias to follow another person's eye-gaze. Preliminary ASD findings suggest that within the context of a flicker task eyes are neither prioritized nor followed. Implications for research methodology are discussed.

Keywords: Social Attention; Autism Spectrum Disorder; Eye-Gaze Following; Flicker Task

Dedication

I dedicate this thesis to my family (Richard, Sebastian, Norah, Peter, Colin and Julia) in thanks for their unwavering patience, love and support as I completed this dissertation.

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List of Acronyms

ASD	Autism Spectrum Disorder
TD	Typically Developing
RT	Reaction Time

Glossary

Gaze-Following	Following another person's eye-gaze towards an object or location in the environment. Within the context of this dissertation, gaze-following involves shifting/orienting of visual attention towards a gazed-at object and is referred to as orienting to gaze which is distinct from the social behaviour of gaze-following.
Gaze-Selection	Focusing on another person's eyes to the exclusion of other visual stimuli in the environment. Within the context of this dissertation, gaze-selection involves selectively attending to visual stimuli of eyes. Gaze-selection and gaze-following are both components of social attention.

1. Introduction

1.1. Thesis Overview

Autism Spectrum Disorder (ASD) is neuro-developmental disorder characterized by two major symptom clusters: 1. persistent impairments in reciprocal social communication and interaction, and, 2. restricted, repetitive patterns of interests, behaviours, or activities (American Psychiatric Association, 2013). These features are present from early childhood and cause significant impairments in everyday functioning. The term *spectrum* refers to the broad variation in manifestations of the disorder in terms of severity as well as its varying presentation across developmental levels and/or chronological age. ASD represents a growing public health concern and the American Centre for Disease control estimates that the disorder currently affects approximately 1 in 88 children. In 2011, ASDs cost the province of British Columbia approximately 165 million dollars (L. Bowness, personal communication, October 12, 2011). As such, significant research efforts have been directed at understanding the neuro-cognitive correlates of the disorder, with the aim of informing early identification and intervention. One early emerging and central symptom of ASD is deficits in gaze-following which occur during social interactions.

This thesis explores whether there are attentional deficits that underlie deficits in gaze-following during social interactions in ASD. In particular, selective attention to gaze and arrow cues (attending to eyes or arrows to the exclusion of other stimuli) and orienting in response to gaze and arrows (shifting attention in the direction indicated by and eye-gaze or arrow cue) within the context of a flicker paradigm using naturalistic scenes. Selective attention difficulties for eye-gaze in ASD have been documented in several studies (e.g. Kikuchi, Senju, Tojo, Osanai & Hasegawa, 2009; Klin et al., 2002; Riby &

Hancock, 2008). Selection is particularly relevant as it may be implicated in the eye gaze following behaviour deficits often associated with ASD (Birmingham, Ristic & Kingstone, 2012). This thesis explores the possibility that standard laboratory attention tasks used to measure gaze following may lack sensitivity to differences in the manner in which individuals with ASD may prioritize (select) social information (i.e. eye-gaze) over non-social information. In particular, this thesis introduces the element of selection into an established computerized paradigm to test the role of differences in gaze-selection biases on orienting to attention during gaze-following behaviour. The aim was to design a task with increased ecological validity and sensitivity to detect differences in attention orienting. Computerized tasks have the potential to add to our knowledge of attention shifts associated with gaze-following in ways that are distinct from observations of social interactions. For example, voluntary as well as involuntary attentional responses can be characterized (e.g. time course), and relations to gaze-following behaviour may be explored.

In **Chapters 2 – 5**, orienting in response to gaze cues (hereafter referred to as orienting to gaze) is explored in typically developing (TD) adults. A consequence of past studies largely minimizing the role of gaze-selection is that little is known about how gaze information is typically prioritized relative to other directional cues. In particular, very few tasks have included a comparison cue (e.g. an arrow) allowing a researcher to gauge how eye-gaze may be prioritized over non-social information. In **Chapter 2**, I explore how TD adults prioritize eye-gaze as compared with arrow cues, by presenting singular cues within scenes. This is done to explore the hypothesis that singular directional cues do not place sufficient demands upon selection and therefore may not reveal potential social prioritization. In **Chapter 3**, I further increase demands on selection by presenting conflicting eye-gaze and arrow cues within the same task so that cues compete for attention. In **Chapter 4 and 5,** I explore gaze-following in greater depth by examining the time course of gaze selection and gaze following effects and the effects of visual saliency upon gaze-following, respectively. In order to gauge whether or not these tasks demonstrate sensitivity to ASD characteristics, across **Chapters 2 – 5,** I examine the relationship between strength of autistic traits in TD adults and the magnitude of gaze selection and gaze following effects. Finally, in **Chapter 6,** I measure gaze-selection and gaze-following in participants with a clinical diagnosis of ASD, in an attempt to clarify the nature of the gaze-following deficits that are thought to characterize this disorder.

1.2. Literature Review

Here the literature on the typical and atypical development of gaze-following is reviewed and orienting to gaze cues in a laboratory task is contrasted with gaze following as a social behaviour in interactive contexts.

1.2.1. Theoretical models of gaze-following in typical development

Theoretical models of typical social-communicative development often highlight the importance of gaze-following vis-à-vis it's role in *joint-attention* and subsequent language and social cognitive development. Similar to *gaze-following*, which is defined as the shifting of attention in response to an averted eye-gaze cue towards a gazed-at object or location in the environment (Birmingham & Kingstone, 2009), joint-attention refers to the ability to share attention with another person in a coordinated manner (Scaife & Bruner, 1975). A typical joint attention response is described as a child following an adult's (i.e. the examiner's) eyes and face (i.e. gaze) towards a target object and then checking back with the adult to ensure that they are sharing attention on the same target.

Mundy (2013) offers a two-stage theoretical model of joint-attention, linking it to the development of gaze following ability. According to his theory, within the first year of life, infants first learn to effectively follow another person's eye-gaze by integrating their executive, motivational and imitative processes in order to support efficient (i.e. rapid and routine) coordination of visual attention with other people. This stage is referred to as the "learning to" process of gaze-following/joint-attention. Moving into the second year of life, children start a "learning from" phase of joint-attention. During this phase, children have better mastery of their gaze-following behaviour and can monitor their own experience and integrate this with information about others during instances of joint-attention. Thus, during the second year of life, children have access to information about their own visual experience and that of others, as well as the ability to reflect upon this knowledge. Arguably, this sets the stage for understanding the convergence and divergence of self and other experience, lending to enriched symbolic understanding and social cognition. Thus, movement from the “learning to” stage (i.e. rapid, routine, and effective gaze-following) to the “learning from” stage (i.e. use of gaze-following to understand that others have mental representations accompanying visual attention) may characterize the acquisition more complex social understanding.

Underscoring the importance of gaze following to typical social development, individual differences in gaze following in infancy are consistently found to predict language development later in life (Morales, Mundy, Delgado, Yale, Messinger, et al., 2000; Morales, Mundy, Delgado, Yale, Neal, et al., 2000). This is thought to occur because gaze-following allows a child to establish reference with a social partner and match verbal utterances with gazed-at objects (Baldwin, 1995). Sensitivity to the social meaning of gaze-direction continues to develop into adulthood (Baron-Cohen, Wheelwright, & Jolliffe, 1997; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) and is a predictor of adult social competence (Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Mundy & Sigman, 2006). For example, gaze-following supports complex forms of social reasoning such as determining social status within a group (Chance, 1967), detecting if someone is lying (Whiten, 1996) and taking another person’s perspective in order to infer their mental state or “mindread” (Whiten, 1997).

1.2.2. Theoretical models of gaze-following in ASD

Given gaze-following’s role in typical social development, several theoretical models of ASD implicate atypical gaze-following as triggering cascading deficits in reciprocal social communication. According to Mundy (2013), gaze-following within the context of joint-attention represents a pivotal skill in ASD because improvement in this skill leads to broad positive changes in social learning. By the same token, impairment in gaze-following/joint-attention severely limits the ability of children with ASD to learn social cognitive/communication skills. Thus, joint attention theoretically serves as a foundation for healthy social-cognitive development, whereas impairments in gaze-following vis-à-vis their impact upon joint attention may lead to disrupted social development in ASD.

Several theories of ASD align with the view that gaze-following deficits play a pivotal role in the pathology of ASD via disturbing the normal acquisition of social communication skills. For example, Baron-Cohen (1995) was the first to propose that gaze-following deficits in ASD may lead to deficits in theory of mind, or the ability to make attributions about the mental states of others. Baron-Cohen proposed a modular theory with hypothetical neurocognitive mechanisms that have evolved to prioritize and calculate the attentional focus of other people. These mechanisms support the sharing of attention, which allows for establishing theory of mind or "mind reading". Theoretically, there are several components of the "mind reading system". The two components associated with social attention are: 1. The EDD (Eye Direction Detector) that rapidly and automatically detects the presence of eyes and computes eye direction (i.e. "is someone looking at you or elsewhere?"), and 2. The SAM (Shared Attention Mechanism) that allows for establishment of shared attention by triggering an obligatory shift of attention in the direction indicated by another person's gaze (as computed by the EDD) and confirming that you and the other person are attending to the same thing. The SAM facilitates the use of social attention in order to infer the intentions and desires of others via the Intentionality Detector (ID) and delivers this information into the Theory-of-Mind Mechanism (ToMM) so that complex attributions of mental state can be made (e.g., what is the other person pretending, knowing, thinking, believing, etc.). Taken together, Baron-Cohen's model places gaze-selection (prioritization of eyes over other visual stimuli in an environment) and gaze-following at the centre of social cognition; they allow for sharing of attention which then facilitates higher order social abilities. In the case of ASD, Baron-Cohen argues that several, if not all of the "mind-reading" modules are impaired which results in "blindness" to the social significance of averted eye gaze.

More recent theoretical models of ASD also implicate gaze-following deficits in the social pathology associated with the disorder. In particular, these theories highlight the role of the prioritization of social information within the context of a dynamic interplay between an individual and their social environment. For example, Klin, Jones, Schultz, and Volkmar (2003) offered a theory called the "enactive mind" (EM) approach. According to this view, when interacting with the social world, TD children perceive what is salient to them (i.e. eye-gaze) and ignore what is irrelevant (e.g. light fixtures) based upon their experience of what has been socially adaptive. Such early social preferences lay the foundation for the development of more complex social cognition, such as mental representations, because this continues to be adaptive within the social environment. In the case of ASD, this process is atypical because social stimuli are not prioritized. Thus, according to the EM theory, in ASD acquisition of language and social concepts must occur via an alternate and arguably less efficient route. In its emphasis upon prioritization of social information, the EM theory (2003) aligns with the Social Motivation Theory (SMT) of ASD proposed by (Dawson, 2008; Dawson et al., 2005). This SMT theory proposes that social reward is central to the development of reciprocal communication skills. Theoretically, from birth healthy infants are rewarded by attending to social information via the influence of neuropeptides (oxytocin and vasopressin) on the dopaminergic reward system. This reward creates a conditioned preference for social stimuli (e.g. another person's eyes) and anticipatory pleasure associated with attending to social information (e.g. gaze-following). Such preference facilitates the development and fine tuning of brain regions associated with social perceptions (e.g. the STS in the case of gaze perception), lending to increasingly sophisticated coordination of brain regions to support more complex social communication skills (e.g. joint-attention). Thus, according to the SMT, inborn preferences for eyes theoretically interact with environmental contingencies to reinforce early gaze-following which supports more complex social communicative development.

In sum, theoretical models of gaze-following in TD and ASD generally purport that gaze-following supports the healthy acquisition of reciprocal social communication and complex social cognition in TD, and is therefore a pivotal skill. In ASD, gaze-following is theoretically impaired due to the reduced salience of social stimuli (e.g. eyes) and these impairments are thought to lead to disruptions in the acquisition of adaptive social communication skills.

1.2.3. Measuring gaze-following and orienting to gaze cues in typical development and ASD

1.2.3.1. Interactive laboratory studies of gaze following

Typical Development

In interactive laboratory studies of gaze following, the basic set up is as follows: the child sits across from an experimenter, who then ensures that they have the child's attention and eye-contact. The experimenter will then look towards an interesting object or location in the room. The interaction will be videotaped and an independent rater will code the videotape for instances of gaze-following (i.e., the infant shifts his/her attention in the direction of the experimenter's gaze). A large body of research using this paradigm suggests that by 3 months of age infants can consistently follow gaze shifts (but only when accompanied by the adult turning his/her head) towards close targets in the visual field but not towards moving targets (D'Entremont, 2000). Using a combination of interactive tasks and computerized presentations of faces, the specifics of the emergence of gaze-following in early development have been identified. By 6 months of age, infants consistently react to shifts in gaze and head direction (D'Entremont, 2000; Hood, Willen, & Driver, 1998; Symons, Hains, & Muir, 1998) but do not follow gaze and head turns to interesting events occurring outside their visual field (Corkum & Moore, 1995). This early gaze-following is dependent upon contextual cues such as the need for prior eye-contact with the gazer (Farroni, Mansfield, Lai, & Johnson, 2003), motion of the pupils (Farroni, Johnson, Brockbank, & Simion, 2000; Moore, Angelopoulos, & Bennett, 1997), and the visual properties of the gazed-at object that make it more or less interesting to look at (Deák, Flom, & Pick, 2000). Although there is no consensus, many studies estimate that gaze-following without the need for an accompanying head turn emerges at approximately 9 months of age (Butterworth, 2004). An adult-like gaze-following response (consistent spontaneous following without the need for pupil motion, even towards objects that are not within view) is seen in children ranging from 12 to 14 months of age (Corkum & Moore, 1995; Farroni et al., 2000). Thus, the emergence of typical gaze-following appears to be a gradual developmental process that unfolds as an infant interacts with his/her social environment (Müller & Carpendale, 2004).

ASD

Using interactive laboratory methods, several studies have consistently documented deficits in gaze-following in participants with ASD as compared with TD or developmentally delayed comparisons. For example, Dawson, Meltzoff, Osterling, Rinaldi, and Brown (1998) compared the ability to share attention (by following the eye-gaze and/or pointing cues of the experimenter) between developmentally matched children with ASD and Down's syndrome (DS). They found that children with ASD (mean age of 5 years) demonstrated impairments in joint attention that were related to (correlated with) their general level of interest in social stimuli. Following this study, Dawson et al. (2004) compared gaze-following in young children with ASD (aged 3-4 years) and those with TD (aged 12-46 months). Gaze-following impairments were noted in the ASD group and were also found to significantly predict language impairments. Leekam, Baron-Cohen, Perrett, Milders, and Brown (1997) similarly examined gaze-following and found that children with ASD were impaired in spontaneous monitoring of gaze-direction as compared with matched TD and DS controls, although they were well able to determine the direction of another person's eye-gaze when explicitly instructed to do so. Following these initial studies, several other interactive lab studies documented impairments or significant delays in gaze-following in participants with ASD as compared with their peers (Bar-Haim, Shulman, Lamy, & Reuveni, 2006; Baron-Cohen, Cox, Baird, Sweettenham, & Nighingale, 1996; Charman et al., 1997; Dawson et al., 1998; Dawson et al., 2004; Leekam et al., 1997; Leekam, Hunnisett, & Moore, 1998; Mundy, Sigman, & Kasari, 1990; Sigman, Mundy, Sherman, & Ungerer, 1986). Research also indicates that individual differences in gaze-following predict symptom severity (Mundy, Sigman, & Kasari, 1994) and long-term social and communication outcomes for children with ASD (Sigman & Ruskin, 1999). Taken together, there appears to be broad support from interactive lab studies that gaze-following deficits exist in ASD and may influence the development of reciprocal communication skills.

1.2.3.2. Computerized gaze-following tasks

Following evidence of gaze-following impairments/developmental delays from interactive lab tasks, researchers have hypothesized that attentional difficulties may underlie these behavioural deficits. Starting in the late 1990s, there was a move beyond observation of gaze-following in natural or semi-natural social environments towards trying to understand the attentional mechanisms underlying the behaviour using computer tasks. Three major computerized methods have been utilized to examine attention shifts associated with gaze-following (Ames & Fletcher-Watson, 2010): *spatial cueing tasks*, *change-blindness methods*, and *eye-tracking during scene viewing*. With the exception of a handful of studies, most findings indicate that participants with ASD follow eye-gaze in a manner that is indistinguishable from their TD peers, leading to a puzzling paradox of impaired real-life gaze-following but intact performance on computerized tasks.

Spatial cueing tasks

To study the attentional mechanisms of gaze following in a more controlled manner, researchers adapted the spatial cueing task (Posner, 1980) into the *gaze-cueing* task (Friesen & Kingstone, 1998). The gaze-cueing task is based on the principle that humans are faster to detect targets in attended locations versus unattended locations. Participants are asked to fixate on the center of a computer screen (the display also often contains a central fixation cross with boxes on the right and left). A gaze cue is then presented which usually consists of either a schematic face or a photorealistic face with pupils looking to the right or the left. After a short delay (hereafter referred to as a *cue-to-target delay*) the target will appear in one of the boxes. The participant is asked to respond by pressing a key as soon as they detect the target. A cue is considered *valid* if it accurately indicates the upcoming location of the target, and *invalid* if it indicates the opposite box from where the target eventually appears. Interpreting findings from a spatial-cueing task is relatively simple: slower target detection for invalid cues relative to valid cues occurs because in order to detect a target at the non-cued location, attention must be shifted away from the cued location and then to the uncued location in order to detect the target. Thus, when participants demonstrate a *validity effect* by exhibiting faster detection of targets appearing at cued vs. uncued locations, this indicates that attention was shifted in response to the cue. Please see Figure 1.1 for an illustration of a typical gaze-cueing task.

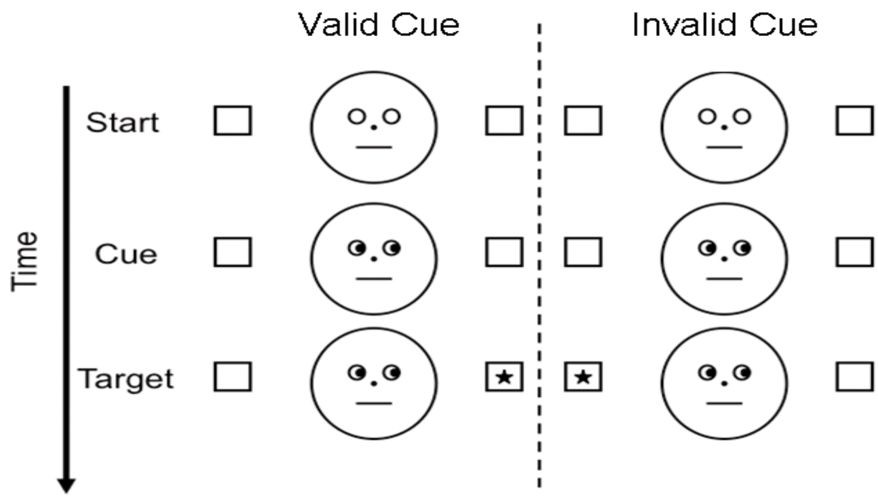


Figure 1.1. Example of a gaze-cueing task with schematic stimuli. This figure is adapted with permission from Birmingham & Kingstone (2009).

Attention shifts on spatial cueing tasks have been classified into two major categories. *Reflexive* orienting of attention is traditionally associated with *non-predictive* (of target location) spatial or peripheral cues such as a flash of light on the screen and is thought to be stimulus driven and involuntary. On the other hand, *volitional* orienting is associated with *predictive* (of target location) directional cues such as a central arrow and is thought to be a goal-driven process (Jonides, 1980). In addition to cue type, reflexive and volitional orienting are differentiated by their time course (i.e., appearance at different cue-to-target delay times). Reflexive orienting occurs quickly (i.e., at cue-to-target delays of approximately 100 – 300 ms), is short lived (i.e., disappears by 700 ms to 800 ms) and is obligatory (i.e., participants cannot stop shifting their attention in the cued direction, even if the cue does not reliably predict the target location) (Müller & Rabbitt, 1989). In contrast, volitional orienting, which is slower to engage, is typically found only at longer (i.e. >300 ms) cue-to-target delays. Unlike reflexive orienting, volitional orienting is susceptible to cue/target contingencies and diminishes when cues are not generally predictive of target location.

Typical Development

Initial findings from gaze-cueing tasks indicated that typically developing individuals reflexively shift their attention in the direction indicated by another person's eye-gaze. In particular, participants demonstrated fast validity effects even when valid cues occurred at low frequencies (Friesen & Kingstone, 1998). This was the first time that reflexive shifting of attention had been observed in response to a non-predictive directional cue (Jonides & Irwin, 1981). To explain their finding, Friesen and Kingstone (1998) proposed that perceiving another person's averted gaze triggers a reflexive shift of attention in the gazed-at direction because gaze-direction is a highly important social cue. Following this initial discovery, several other studies replicated the finding of fast (100 to 300 ms) and seemingly involuntary (occurring when cue is not spatially predictive) orienting in response to gaze-cues within the gaze-cueing task (Driver et al., 1999; Friesen & Kingstone, 1998, 2003a, 2003b; Friesen, Moore, & Kingstone, 2005; Friesen, Ristic, & Kingstone, 2004; Langton & Bruce, 1999, 2000). In particular, gaze cues elicited very rapid, as fast as 14 ms after cue onset (Hietanen & Leppänen, 2003), shifting of spatial attention even when cues were counter-predictive of target location (i.e., the target was more likely to occur at the location *opposite* the cue; (Friesen et al., 2004). Reflexive orienting was subsequently observed in infants (Farroni et al., 2000; Hood et al., 1998) and children (Ristic, Friesen, & Kingstone, 2002). Thus, gaze-cueing task appeared to tap into the human sensitivity to averted eye-gaze by measuring the speed of orienting under highly controlled situations, with researchers claiming that this orienting effect was unique to gaze cues due to their social importance (Langton, Watt, & Bruce, 2000).

ASD

The gaze-cueing task was soon applied to the ASD population to examine whether deficits in orienting to gaze cues would be exhibited. Contrary to predictions, thirteen gaze-cueing studies indicated that participants with ASD followed eye-gaze cues in a manner that was indistinguishable from that of the comparison groups (Chawarska, Klin, & Volkmar, 2003; de Jong, van Engeland, & Kemner, 2008; Kuhn et al., 2010; Kylliäinen & Hietanen, 2004; Okada et al., 2002; Pruett et al., 2011; Rombough & Iarocci, 2013; Rutherford & Krysko, 2008; Senju, Tojo, Dairoku, & Hasegawa, 2004; Stauder, Bosch, & Nuij, 2011; Swettenham, Condie, Campbell, Milne, & Coleman, 2003; Uono, Sato, & Toichi, 2009; Vlamings, Stauder, van Son, & Mottron, 2005). Whereas a handful of studies have found reduced gaze-cueing in participants with ASD as compared with typical or developmentally delayed controls (Gillespie-Lynch, Elias, Escudero, Hutman, & Johnson, 2013; Goldberg et al., 2008; Johnson et al., 2005; Ristic et al., 2005), the majority of the evidence suggests that gaze-following is intact in participants with ASD. A recent meta-analysis on effect sizes for gaze-cueing confirms that participants with ASD are less impaired on gaze-cueing tasks as compared with other types of cueing tasks (Landry & Parker, 2013). Several review papers (Ames & Fletcher-Watson, 2010; Birmingham, Ristic, & Kingstone, 2012; Nation & Penny, 2008) have examined the evidence from gaze-cueing tasks in an attempt to clarify why most studies have reported intact gaze-following in ASD, despite impaired gaze-following being a clinical characteristic of the disorder (American Psychiatric Association, 2013).

Nation and Penny (2008) reviewed seven gaze-cueing studies (i.e. Chawarska, Klin, & Volkma, 2003; Johnson et al., 2005; Kylliainen & Hietanen, 200; Okada et al., 2002; Ristic et al., 2005; Senju, Tojo, Diaroku, & Hasagawa, 2004; Swettenham, Condie, Campbell, Milne, & Coleman, 2003; Vlamings, Stauder, van Son, & Mottron, 2005). Within their review paper, Nation and Penny explored explanations for the counterintuitive findings of intact gaze-cueing. For example, they examined the possibility that gaze-cueing may appear intact because it is most frequently studied in older children with high functioning ASD, whereas gaze-following deficits (when they are observed within the context of social behaviour in an interactive setting) are most pronounced in younger and more highly impaired individuals with ASD. However, they then note that this explanation is suspect given that a few studies have actively documented intact gaze-cueing effects despite real-world gaze-following impairments in very young children (Chawarska et al., 2003; Okada et al., 2002). For example, Chawarska and colleagues (2003) were one of the first groups to test gaze-cueing in low functioning young children with ASD and used a dynamic gaze cue. They compared the gaze-cueing performance of 2 year-old children with ASD with performance of TD control children. Gaze-cueing stimuli consisted of a dynamic display of a colour photographs that looked forward, blinked, and then looked to the right or the left. Targets consisted of photographs of toys and children's characters. Both groups of children (ASD, TD) demonstrated a validity effect (i.e. faster detection of gazed at targets over non gazed at targets), despite lack of cue predictiveness (50% validity). However, prior to participating in gaze-cueing, a lack of spontaneous gaze-following was confirmed in the ASD children using an interactive (face-to-face) social task. Similarly, Okada and colleagues (2002) found intact gaze-following in children with ASD who demonstrated real-life gaze-following impairments. Thus, there is little support for the notion that intact gaze-cueing occurs only in older high-functioning individuals with ASD. Similarly, Birmingham, Ristic & Kingstone (2012) reviewed the literature and reported that intact gaze-cueing effects found in individuals with ASD cannot be accounted for by factors such as the presence of motion cues, differences in stimulus type (schematic vs. photograph), or variations in chronological or mental age of participants.

Following these review papers, four studies have since been published, one showing impaired gaze-following in children with ASD (Gillespie-Lynch et al., 2013), two showing intact gaze-cueing in individuals with ASD (Pruett et al., 2011; Rombough & Iarocci, 2013), and one showing subtle differences in the laterality of gaze-cueing effects (Stauder et al., 2011). Gillespie-Lynch and colleagues (2013) found evidence of impairments in reflexive gaze-following in 4-year-old children with ASD (n=21) as compared with non-verbal mental age matched TD children (n=21). In particular, these researchers measured gaze-cueing using a task similar to that used by Chawarska et al. (2003), except that Gillespie-Lynch and colleagues manipulated the emotional expression of the photorealistic face giving the gaze cue (i.e. faces were either happy, fearful, or neutral) although only neutral cues were used in the analysis of gaze-cueing effects. At the shortest cue-to-target delay time (167 ms), comparison children demonstrated a validity effect for gaze, but this was not found in children with ASD. Thus, children with ASD appeared to exhibit impaired reflexive gaze-following on this cueing task.

In contrast with Gillespie-Lynch et al.'s findings, two recent studies have found intact gaze-cueing in ASD. Pruett and colleagues (2011) compared covert orienting for peripheral vs. central gaze and arrow cues, using both reaction time and eye- tracking methods within a cueing task over a series of three experiments. They manipulated cue probability for all cue conditions (i.e. cues were either 50% or 80% valid). In their third experiment, Pruett et al (2011) compared orienting in 25 TD children to 27 children with high functioning ASD. Although children with ASD made more eye movements, which slowed their mean reaction time, they demonstrated intact gaze-cueing. In particular, like TD comparisons, children with ASD demonstrated a significant validity effect at the shortest cue-to-target delay time (150 ms), indicating that their attention had been reflexively directed by the gaze cue. Similarly, Rombough and Iarocci (2013) found that children with high functioning ASD demonstrated intact reflexive gaze-cueing, using similar methods and stimuli as those employed by Ristic et al. (2005), who in contrast had reported a lack of reflexive gaze-cueing in adults with ASD. In Rombough and Iarocci's study, children with ASD (n=25) demonstrated equivalent performance to TD comparison children (n=25) on the gaze-cueing task, despite showing impairments in their social use of gaze on another task. In particular, children's ability to understand the social meaning of eye-gaze vs. arrows was measured and children with ASD were found to be impaired in using eye-gaze to make inferences about a character's mental state or state of reference, preferring to follow a non-social arrow cue instead. Thus, despite demonstrated deficits in use of eye-gaze for social purposes (e.g. establishing reference), children with ASD demonstrated intact gaze-cueing, suggesting that the gaze-cueing task may lack sensitivity to ASD deficits in prioritization of eyes for social communication. Taken together, these more recent findings suggest that the gaze-cueing task may be variably sensitive to gaze-following related impairments in ASD; one study shows impairments while two show intact performance.

Another recent publication by Stauder, Bosch and Nuiji (2011) found subtle gaze-cueing differences associated with ASD. They compared validity effects for arrows vs. gaze cues in children with ASD (n=22) and matched TD comparisons (n=22). Although the ASD group showed intact cueing effects for both gaze and arrow cues they found slight variation in the laterality of validity effects. In particular, for TD comparisons, validity effects were found for right visual field cueing (but not left side) with gaze cues. In contrast, validity effects were found for left visual field cueing (but not right) in children with ASD. Important to the present dissertation, the Stauder et al. (2011) paper raises the interesting possibility that cueing differences can be detected with the use of a comparison arrow within a cueing task. Review papers by Ames and Fletcher-Watson (2010) and Nation and Penny (2008) suggest that use of comparison arrows can reveal subtle ways in which participants with ASD do not treat social stimuli (eyes) in a manner that is different from non-social stimuli (arrows). For example, Ames and Fletcher-Watson (2010) note that ASD differences in gaze-cueing tend to emerge when an arrow cue is used. They note that TD comparisons tend to show a greater validity effect for eyes over arrows, whereas eyes and arrows often elicit comparable cueing effects in ASD (Senju et al., 2004; Vlamings et al., 2005). However, Birmingham et al. (2012) challenge this notion by citing evidence that “ASD-like” patterns of equal gaze and arrow cueing have also been observed in TD participants (Bayliss & Tipper, 2005; Tipples, 2002, 2008) and therefore do not necessarily reflect relative insensitivity to social cues in individuals with ASD.

Change-blindness tasks

An alternate computerized method that has been used to examine how attention is shifted in response to eye-gaze cues is the change-blindness task. The most common type of change detection task is a *flicker task* wherein participants are shown two images of the same scene on a computer screen. One of these images is an original and the other contains a change (such as the disappearance of an object); the participant’s goal is to quickly and accurately detect the change in the scene. Importantly, separating the presentation of the two scenes is a blank screen, leading to a “flicker” effect. Most people tend to find the task surprisingly difficult with change detection times reaching as long as twenty seconds (Shapiro, 2000). This phenomenon is referred to as “change blindness”, which is thought to occur because the blank screen obscures the movement cue that would typically draw attention to the change (Rensink, O'Regan, & Clark, 1997). Thus, change detection tasks operate upon the principal that focused attention is required to detect specific changes within a visual scene (Rensink, 2002): because no movement cue is available, participants must move their attention deliberately about the scene until they find the change. The researcher is therefore able to use a flicker task to gauge the location of visual attention because changes to attended areas are detected faster and more accurately than changes to unattended areas (Simons, 2000). Attention for scene locations/objects is measured by examining reaction times (RT) and or accuracy for changes to these areas/objects. When changes to an area/object are detected quickly and accurately, this is thought to represent the attentional prioritization of this screen location. In contrast, when changes are associated with relatively slow (often as compared with a control change) or inaccurate detection, attention for the changing object is arguably less of a priority.

Typical Development

Langton, O'Donnell, Riby, and Ballantyne (2006) pioneered the use of the flicker task to measure gaze-following in adults with typical development. Their stimuli consisted of three scenes that contained a centrally located person with head and eyes pointing towards an area of the scene. Changes consisted of the removal of an object from the margins of the scene. Results from their first experiment, a between subjects design, indicated that participants were faster to detect changes made to gazed-at than non-gazed-at objects. Furthermore, there was a linear deterioration in change detection performance as the changing object was located progressively further away from the direction of gaze. Results from their second experiment, wherein scenes were repeatedly shown to the same subjects, indicated that participants detected 88% of gazed-at changes as compared with 44% of non-gazed-at changes. Findings were interpreted as indicating spontaneous orienting to gaze within realistic scenes. It was hypothesized that following another person’s eye-gaze towards objects that s/he is looking at is spontaneously prioritized by the human attention system based upon the communicative importance of gaze during everyday social interactions. Thus, Langton’s findings align with outcomes from gaze-cueing tasks using participants with typical development.

ASD

Freeth, Ropar, Chapman, and Mitchell (2010) subsequently used the flicker task to investigate gaze-following in adolescents with ASD. Similar to Langton et al.'s (2006) study, stimuli consisted of eight scenes with a centrally located person. The person within the scene either gazed straight ahead (on neutral trials) or at one of three possible (changing) objects located on a table in front of them. Results indicated that *all participants* (both with ASD and TD controls) were faster to notice changes to objects in gazed-at locations. Freeth and colleagues concluded that participants with ASD show spontaneous orienting to gaze during realistic scene viewing in a manner that is indistinguishable from TD comparisons.

More recently, Sheth et al. (2011) used the flicker task to examine social attention (including orienting to gaze) in children and adults with and without ASD. Participants viewed 6 different types of scenes including: 1. changes to an object with no human present, 2. changes to a human-unrelated object (e.g. a stapler on a desk), 3. changes to a human-related object (e.g. a person's clothes change), 4. changes to an attended object (indicated by either looking, pointing, or touch), 5. changes to a non-attended object (social cue is misdirecting), or 6. changes to a human face. Scenes varied randomly in their social content, in terms of number of people with various levels of social interaction. The authors did not analyze trends between conditions, but graphs suggest that changes to human faces were detected the fastest, followed by socially cued object (changes cued by gaze direction head-direction, or a finger point), followed by object changes with no humans in the scene, followed by a human un-related object, a non-attended object, and a human-related object. Participants' responses, especially those of children, appeared to be slowed by misleading social cues (suggesting that they were spontaneously following social cues). Perhaps most strikingly, participants with ASD and TD performed equivalently.

Taken together, the findings of Freeth, Ropar, et al. (2010) and Sheth et al. (2011) indicate that on flicker tasks participants with ASD spontaneously orienting to gaze in a manner that is indistinguishable from TD comparisons. Thus, flicker task findings align with gaze-cueing findings showing intact gaze-following despite conflicting evidence of gaze-following deficits during social interactions.

Scene viewing tasks

Another computerized method that has been used to investigate how participants with ASD follow eye-gaze is the recording of eye-movements during scene viewing (hereafter referred to as *scene viewing tasks*). Eye-movements are thought to offer a good approximation of a person's visual attention, at least in participants with typical development (Kowler, Anderson, Dosher, & Blaser, 1995). Therefore, using an eye-tracker to monitor the fixations (focus of eye) and saccades (movements of the eye) of participants can inform researchers about a participant's visual priorities while they are viewing a scene. Scenes are typically photographs including one or more persons or alternatively, dynamic images with people. Some advantages of this method are that the temporal and spatial patterns of visual attention during scene viewing are readily available to researchers.

Typical Development

There is some evidence from scene viewing tasks that typically developing adults spontaneously orient to gaze when viewing a person within a photograph. For example, (Fletcher-Watson, Findlay, Leekam, & Benson, 2008) measured eye-movements of TD adult participants during static scene viewing. Several scenes contained a single person and participants were allowed to freely view the scenes. Findings indicated that there was a strong bias to initially fixate upon the person within in the scene, and especially their face. Following this initial fixation upon faces, there was a significant bias to look at the object that was being looked at by the person within the scene, in other words, to orient to the gaze-cue. Thus, TD adults appear to prioritize gaze-following when viewing scenes which contain a person. Similarly, Klin et al. (2003) examined following of the combined gaze and pointing of an actor within a movie scene using eye-movement tracking in at least one male adolescent with high functioning ASD and a TD comparison. Whereas the scan path (saccades) of the TD participant indicated that they oriented to the actor's gaze cue towards an object (a painting on the wall), the participant with ASD did not orient to gaze and instead scanned the wall randomly when they heard the accompanying audio cue (i.e. "Who did that painting?").

ASD

As Klin and colleagues' (2003) work suggests, scene viewing tasks conducted on individuals with ASD have revealed some differences/impairments in orienting to gaze. For example, Fletcher-Watson, Leekam, Benson, Frank, and Findlay (2009) measured gaze-following within a scene viewing task in 12 adolescents with ASD and compared with 15 TD matched comparison participants. Stimuli consisted of a 40 displays with a scene containing a person on one side and a scene with no person on the other side, separated by a dark line. Participants were first instructed to freely view the scenes while their eye-movements were recorded. Then, participants were asked to identify the gender of the person within the scene. Results indicated that TD participants were more likely to first fixate upon scenes containing people and this tendency increased during the gender discrimination task. A subtle difference was found for the ASD group who demonstrated a less robust preference for social stimuli during the first fixation. In terms of orienting to gaze, participants with ASD did not demonstrate any shifting of attention in the gazed-at direction. TD participants demonstrated orienting to gaze (i.e. looking at the object being looked at by the person within the scene) only during the free viewing condition and not during the gender discrimination task. Visual saliency analysis confirmed that the low-level features within the scenes (e.g. luminance, contrast) did not predict eye-movements for either group. Overall, Fletcher-Watson et al.'s study suggests that participants with ASD have a less robust initial bias to focus upon people within scenes and demonstrate lack of orienting to eye gaze. These findings are in keeping with observations of impaired gaze-following in ASD within clinical and naturalistic setting, suggesting that Fletcher-Watson's task was sensitive to these differences. However, the effects of eye-gaze are difficult to interpret without a comparison cue. Possibly, TD participants were simply following the only directional cue within the scene, and this following was unrelated to the social significance of eye-gaze. It's also possible that participants with ASD may have a general deficit in following directional cues that is not specific to orienting to eye-gaze. The unique effects of eye-gaze on following behaviour within complex scenes may only be discernible with the inclusion of a non-social control cue.

In contrast with Fletcher-Watson et al.'s findings, another scene-viewing task has found intact gaze-following in ASD. Freeth, Chapman, Ropar, and Mitchell (2010) studied gaze-following within a scene viewing task in 24 adolescents with ASD and 24 TD comparisons. Scenes were photographs containing a person who was looking straight forward or towards an object within the scene. Eye-tracking equipment monitored the duration, timing, and sequence of fixations. Results indicated that both groups spent the same amount of time looking at the upper face area (which contains the eyes) of the person within the scene. However, similar to Fletcher-Watson et al. (2009), time course analysis revealed that TD participants were more likely than ASD participants to allocate their first fixation to faces. Both groups demonstrated orienting to eye-gaze. . However, ASD participants spent less time than TD participants fixating upon the gazed-at object. Taken together, this study suggests that participants with ASD prioritize and orient to eye-gaze in a similar manner to their TD peers but that subtle differences in timing of the response may exist. These findings hint to the possibility that subtle differences in prioritization of eye-gaze are evident when gaze-selection and orienting to eye-gaze cues are measured together and when the time course of gaze-following is considered.

1.2.4. Can we maintain experimental control yet increase ecologically validity of computerized eye gaze tasks?

Collectively, evidence from attention tasks (i.e. gaze-cueing, flicker, and scene viewing tasks), have not indicated any deficits in orienting to gaze cues in people with ASD. Some theorists have proposed that real-world gaze-following deficits (i.e. social behaviour that occurs within the context of a social interaction) are attributable to impairments in an area other than attention orienting such as initiation of joint attention (Mundy, 2013), or social motivation (Leekam et al., 1997), which are not measured in computerized tasks. Thus, real world gaze-following deficits may not be associated with attentional differences/impairments in ASD.

In a previous study (Rombough & Iarocci, 2013) I examined the relations between performance on a gaze-cueing task and three gaze-following tasks: 1. an interactive gaze-following scenario which was video-taped and coded, 2. a social-inferencing task (where gaze or arrows could be followed to infer mental state of a cartoon character), and 3. a computerized line of sight follow task where gaze was followed towards objects in an array. When I compared the performance of 25 children with ASD with 25 age, gender, and IQ matched TD comparisons, I found intact gaze-cueing in ASD but impairments on the higher-order gaze-following tasks as well as the spatial line of sight task. In particular, children with ASD were less able to infer social meaning from eye-gaze (they were more likely to use the arrow cue to infer meaning) and had difficulty following eyes towards objects in an array. There were no significant correlations between performances across tasks, for either the ASD or comparison group. I concluded that either: 1. gaze-following (in terms of orienting attention) was an independent skill from higher order abilities to use eye-gaze socially, or 2. the skills are correlated, but the spatial cueing task lacked ecological validity. In support of the first possibility, gaze-cueing likely taps into lower level attention biases, whereas understanding the referential nature of eye-gaze likely involves a number of perceptual, attentional, social and cognitive skills sets (Chawarska et al., 2003). To expand upon the second possibility, in the tasks in which participants had to initially select gaze (i.e. choose to attend to it over an arrow, for example), group differences were found. Thus, contrasting gaze and arrow cues is an important element that needs to be further explored. In addition computerized tasks may be designed to include everyday visual scenes, fast paced and changing conditions and an emphasis on allowing participants to express their natural viewing preferences (i.e. demonstrated gaze-selection) to improve ecological validity to better capture attentional demands of everyday situations.

Most spatial cueing tasks typically present the cue of interest (gaze), in isolation, at the fixation point in the centre of the screen. As a result, the viewer has no choice but to select (orient to) the eyes (as there is nothing else to select). In this manner, this task does not allow participants to express how they may prioritize gaze cues though the process of *selecting the eyes in the first place*. Thus, Birmingham, Ristic and Kingstone (2012) argue that omitting or minimizing the role of gaze-selection renders computerized attention tasks (i.e. the gaze-cueing task) insensitive to potential differences among individuals with and without ASD. Their argument rests upon the notion that gaze-selection is a fundamental aspect of gaze-following that is different in ASD. I now examine the evidence to support this notion below.

1.2.4.1. The role of gaze-selection

Gaze-selection is defined as focusing on another individual's eyes to the exclusion of other visual stimuli. Theoretically, it is an important skill associated with gaze-following and orienting to gaze cues because it allows the viewer to initially notice averted eye-gaze (Birmingham & Kingstone, 2009). Whereas gaze-selection appears to be prioritized by individuals with typical development, this does not appear to be the case in ASD.

Typical Development

Typically developing individuals appear to have a robust bias to attend to the faces and eyes of other people. Almost from birth, humans preferentially attend to eyes over other facial features such as noses and mouths (Haith, Bergman, & Moore, 1977). Evidence from a variety of attention methods indicates that adults also preferentially select eyes over mouths, noses, and other facial features when viewing faces (Henderson, Williams, & Falk, 2005; Pelphrey et al., 2002; Walker-Smith, Gale, & Findlay, 1977). The bias to select faces and eyes remains strong when viewing people embedded within scenes (Birmingham, Bischof, & Kingstone, 2008; Foulsham, Cheng, Tracy, Henrich, & Kingstone, 2010; Klin et al., 2002; Ro, Russell, & Lavie, 2001). For example, Birmingham, Bischof and Kingstone (2008) used scene viewing techniques to measure the attentional biases of TD adults. Scenes contained either one or three people engaged in activity (e.g. reading a book, engaging in a "toast") or inactive (e.g. sitting and gazing into space). Participants were given one of three tasks: 1. freely view the scenes, 2. describe the scenes, or 3. describe where people within the scenes were looking. Results indicated that participants readily attended to the eyes of people within the scenes (i.e. the highest proportion of fixations was on eye-regions) and that gaze-selection increased when the task was more social (i.e. scenes with three people, task was to identify the attention of people within the scene). Thus, Birmingham et al.'s (2008) findings suggest that there appears to be a strong spontaneous prioritization of eye-gaze, which increases as social demands increase. This "eye-bias" has since been observed using eye-tracking during presentation of dynamic scenes/videos (Foulsham et al., 2010) and during "live" social interactions (Foulsham, Walker, & Kingstone, 2011) where it appears to be particularly sensitive to social demands (Gallup et al., 2012; Laidlaw, Foulsham, Kuhn, & Kingstone, 2011).

ASD

Gaze-selection is diminished in ASD relative to TD comparisons, supporting the notion that excluding or trivializing gaze-selection within computerized gaze-following tasks may mask ASD differences. Initial support for diminished gaze-selection in ASD came from a retrospective study examining video-tapes of young children who were later diagnosed with ASD. Osterling and Dawson (1994) coded video-tapes of first birthday parties and found that compared with their TD peers, children who were later diagnosed with ASD spent less time looking at the faces of others. Swettenham et al. (1998) also coded videotapes of children who were engaged in free play and found that children with ASD spent less time looking at people and has a greater tendency to look at objects for longer durations. Leekam and colleagues (2000) and Leekam and Ramsden (2006) found related deficits in dyadic interaction/initiation of joint attention (i.e. attending to another person's eyes in the first place) and triadic attention/response to joint attention (i.e. gaze-following). Following these initial reports, gaze-selection has been examined in ASD using the change detection paradigm (e.g. flicker task) and eye-movement tracking techniques.

Two flicker studies have examined gaze-selection by measuring speed and/or accuracy for detection of changes to the eye-regions of people within scenes, with conflicting results. Kikuchi, Senju, Tojo, Osanai, and Hasegawa (2009) used a flicker task to present photographs of people within scenes to children (aged 7 to 15 years) with ASD and TD comparisons. They found that whereas TD children where faster to detect changes to faces over objects, children with ASD were equally fast to detect changes to faces and objects. Kikuchi and colleagues reasoned that children with ASD may lack the typical prioritization of other people's faces over non-social stimuli, which may be related to their atypical gaze-following. In contrast with Kikuchi et al.'s findings, a flicker task experiment conducted by Fletcher-Watson, Leekam, Findlay, and Stanton (2008) revealed an intact bias to attend to another people's averted eye-gaze during scene viewing. Fletcher-Watson and colleagues presented complex static scenes containing a person. Control changes included changes to the eye region of a person within the scene (i.e. appearance and disappearance of spectacles). Experimental changes included changes to the direction of the person within the scene's averted eye-gaze. Results showed that adult participants with ASD, like TD comparisons, detected eye-gaze changes faster and more accurately than control changes to the eye-region. Fletcher-Watson and colleagues reasoned that the finding of intact gaze-selection was a product of the high developmental level of their participants, given that attention for eye-gaze has been found to vary with age, developmental level, and severity of ASD symptoms (Leekam, López, & Moore, 2000). Possibly, although individuals with ASD have intact abilities to prioritize averted gaze over a general change to the eye-region, they may be less likely to initially prioritize eyes over another directional cue *in the first place*. Testing of this hypothesis would require inclusion of a non-social directional cue, such as an arrow, within the task design.

Studies measuring eye-movement tracking during scene viewing have more consistently detected ASD differences in gaze-selection. For example, Klin et al. (2002) measured eye-movements as adolescent participants with ASD and TD comparisons watched movie clips containing one or more actor. They then coded their data for fixations upon the following screen regions: mouth, eyes, body, and objects. Findings indicated that participants with ASD spent significantly less time focusing upon the eye regions of actors within scenes. Instead, ASD participants attended to mouth, body and objects to a greater extent than their TD peers. Further, the amount of time spent focusing on mouths and eyes were a strong predictor of social competence for participants with ASD. Presenting faces alone, Pelphrey et al. (2002) replicated the finding of less time focusing on core facial features (including eyes), and increased time focusing on socially irrelevant facial areas in adult participants with high-functioning ASD. Similarly, Spezio, Adolphs, Hurley, and Piven (2007) confirmed that adults with ASD fail to focus upon the eyes when asked to make emotion judgements from faces and instead attend to the mouth region. Presenting static photographs of social scenes (e.g. a wedding), Riby and Hancock (2008) also found that participants with ASD spent considerably less time attending to the faces of people within the scenes as compared with TD and developmentally delayed (William's syndrome) comparison participants. Recently, Jones and Klin (2013) used eye-movement tracking to investigate attention for eye in infants who viewed videos. Infants who were later diagnosed with ASD initially demonstrated intact gaze-selection relative to controls. However, Jones and Klin observed a significant decline in gaze-selection in ASD group participants between ages 2 and 6 months. This suggests that gaze-selection may be initially typical but rapidly declines early in the life of individuals on the spectrum. Taken together, it appears that there is convincing evidence to support the notion that gaze-selection is diminished or impaired in ASD.

1.2.4.2. The role of gaze-selection when measuring orienting to gaze cues

Birmingham et al.'s (2012) hypothesis that standard computer tasks lack sensitivity to ASD differences in gaze-following is well supported by the majority findings of intact gaze-following on *gaze-cueing tasks*, which arguably omit the component of gaze-selection by presenting a singular cue at fixation. However, on first pass Birmingham et al.'s (2012) hypothesis is not supported by findings from the *change blindness* and *scene viewing* studies reviewed earlier, which clearly allowed observers to freely select visual information the scene. During a task with realistic scenes, participants must selectively focus upon the eyes of people within the scene to the exclusion of other visual stimuli within the scene. However, in change-blindness studies (Freeth, Ropar, et al., 2010; Sheth et al., 2011), there were no robust deficits in orienting to gaze found in ASD, refuting the hypothesis that allowing observers the freedom to select stimuli will reveal ASD-related differences in gaze following. Similarly, one scene viewing task study has found intact orienting to gaze in ASD despite participants being presented with realistic scenes (Freeth, Chapman, et al., 2010).

At first glance, these findings present problems for Birmingham et al.'s (2012) hypothesis. However, closer examination of the stimuli used in change-blindness and scene viewing tasks suggests that although demands upon selection are greater than in a classic gaze-cueing tasks; gaze-selection demands may not be equivalent to more real life social situations wherein multiple cues may compete for attention and cues need to be followed quickly. For example, Freeth, Ropar, et al. (2010) and Freeth, Chapman, et al. (2010) stimuli consisted of a singular, centrally presented person. Presenting a singular person within a photograph may trivialize the process of gaze-selection because there is only one cue for the participants to follow. Participants may follow this cue within the task although they may not naturally prioritize it in a more real-world setting where other stimuli (e.g. other people, sounds, other directional cues) may compete for their attention. Thus, it's possibly that Freeth and colleagues' stimuli did not stringently test whether ASD-related deficits in orienting to gaze can be revealed by allowing observers the opportunity to select cues from the environment. Although Sheth et al. (2011) did present more varied stimuli (e.g. multiple people within a scene, varied and object rich environments) their results are somewhat difficult to interpret. For example, their "attended object" condition included a mixture of directional cues (e.g. pointing, head turns, and eye-gaze) and in at least one scene, the person also touched the target object. This mixture of cues makes the effects of orienting to gaze difficult to disentangle. Possibly, findings of intact orienting to gaze may be attributable to intact biases to follow pointing, touched objects, or a combination of several social cues.

The two scene viewing tasks that have found ASD differences have arguably placed more demands on selection by presenting either varied and object rich scenes (Fletcher-Watson et al., 2009) and/or multi-modal and dynamic scenes (i.e. movie clips) (Klin, Jones, Schultz & Volkmar, 2003). These two studies found absent orienting to gaze in participants with ASD which supports Birmingham et al.'s (2012) hypothesis that increasing demands on selection may reveal ASD deficits in gaze-following. However, neither of these studies included a comparison cue and the attentional effects of eye-gaze are difficult to evaluate without a control. For example, it's possible that lack of orienting to gaze in Fletcher-Watson et al.'s and Klin et al.'s participants is attributable to a general deficit in following directional cues, rather than a specific deficit for eye-gaze. Therefore, although the literature to date hints that further increasing demands on selection within realistic scenes may help to uncover ASD deficits, in the absence of a control cue, findings are difficult to interpret. Below I propose that introducing a key manipulation – competition between cues – may have twofold benefits; 1. increased selection demands and 2. providing comparison behaviour for interpretation of gaze-following in participants with TD and ASD.

1.2.5. Competition between cues to reveal attentional priorities

Arrow cues have been compared to a variety of eye-gaze cues. They are generally thought of as equivalent to an eye-gaze cue in terms of being directional (i.e. they indicate a direction) but divergent in terms of being non-social. Thus, comparison arrows have the potential to demonstrate how social following behavior may be distinct from non-social following. An additional benefit of arrows is that presenting multiple cues within a scene may force participants to reveal their priorities as they choose one cue over another.

A review of previous research that has compared eye-gaze with arrows indicates that within spatial-cueing tasks, arrows have not consistently been found to elicit a distinct response from eye-gaze. This supports that hypothesis that the spatial-cueing task may lack sensitivity to social preferences/prioritization (Birmingham, Ristic & Kingstone, 2012). In particular, although arrows were initially thought to elicit voluntary orienting within a cueing task (Jonides & Irwin, 1981), arrows cues have since been found to elicit what appears to be reflexive orienting responses that are behaviorally indistinguishable from responses to gaze cues (Hommel, Pratt, Colzato, & Godijn, 2001; Ristic et al., 2002; Tipples, 2002, 2008). Several neuro-cognitive findings (neuroimaging while the participant completes a cueing task) also report identical neural activation by gaze and arrow cues (Brignani, Guzzon, Marzi, & Miniussi, 2009; Tipper, Handy, Giesbrecht, & Kingstone, 2008). Please see Birmingham and Kingston (2009) for a more thorough review of the gaze vs. arrow cueing research. When arrows and eye-gaze are compared within realistic scenes, their effects are strikingly different. Birmingham, Bischof, and Kingstone (2009a) examined the eye-movements of TD adults who viewed of static scenes that contained either a person (or people) and an arrow. Participants were allowed to freely view the photographs. Results clearly indicated that viewers prioritized the eyes of people within the scene (or heads when eyes were not visible) over arrows. In fact, viewers never prioritized arrows (e.g. first fixations were never for arrows). These findings suggest that TD participants have a strong bias to prioritize eyes within realistic scenes and also hint that arrows may serve as a useful comparison cue because they can reveal typical preferences for social stimuli.

The effects of eye-gaze vs. arrow following behaviour have not yet been compared within realistic scenes and their relative effects upon attention orienting are unknown. In this manner, arrows have the potential to elucidate how individuals with both typical and atypical development prioritize social vs. non-social directional cues. In individuals with typical development, it's not known whether gaze-following is prioritized over arrow following. Although theory suggests that gaze-following is uniquely prioritized by the human visual attention system (Perrett, Hietanen, Oram, & Benson, 1992) by virtue of its central role in human development (Baron-Cohen, 1995) and contribution to the social fitness of our species (Emery, 2000), spatial-cueing tasks show equal gaze and arrow following. Therefore, comparing eye-gaze and arrow cues within realistic scenes may clarify typical gaze-following behaviour and the manner in which it may be prioritized.

Central to this dissertation, comparison arrows may also help to uncover ASD differences. First, as previously argued, ASD differences may be uncovered by increasing demands on selection by virtue of having multiple cues competing for attention. Second, relatively abnormal biases for social vs. non-social biases may be revealed. For instance, in more interactive contexts, individuals with ASD do not appear to prioritize gaze-following over arrow-following (Rombough & Iarocci, 2013). It is not currently known whether the same lack of social prioritization will manifest during an attention task with realistic scene viewing.

1.2.6. Summary of literature review

In this review I have demonstrated that individuals with ASD show deficits in gaze-following in interactive settings (e.g. Dawson et al., 1998) and these deficits are associated with the severity of social impairments (e.g. Sigman & Ruskin, 1999), theoretically because poor or absent gaze-following disrupts healthy social communicative development (e.g. Dawson et al., 2005; 2008; Klin et al., 2003; Mundy, 2013). However, when attention to gaze cues is tested using computerized tasks, individuals with ASD generally demonstrate performance that is indistinguishable from their TD peers. A review of findings from spatial cueing tasks indicates that the majority of studies have found intact orienting to gaze cues in participants with ASD despite variation in age, cognitive ability and level of autistic symptoms (Ames & Fletcher-Watson, 2010; Birmingham, Ristic & Kingston, 2012; Nation & Penny, 2008). Similarly, a review of the change-blindness literature (i.e. flicker tasks) reveals findings of intact orienting to eye-gaze (Freeth, Ropar, et al., 2010) and combined social cues (Sheth et al., 2011). Findings from eye-movement tracking tasks are mixed. Whereas, one study has found intact behaviour (Freeth, Chapman, et al., 2010), two have found absent orienting to in participants with ASD (Klin, Jones, Shultz & Volkmar, 2003; Fletcher-Watson et al., 2009).

Birmingham, Ristic & Kingstone (2012) propose that lab based attention tasks lack sensitivity to how people prioritize social information and therefore, not valid measures of social attention. In particular, Birmingham and colleagues argue that gaze-cueing tasks have generally excluded or trivialized gaze-selection (i.e. focusing on another person's eyes to the exclusion of other stimuli) by virtue of presenting de-contexualized faces at fixation. A review of gaze-selection research confirms that attention for the eyes may be a key manner in which attention is different in ASD. Whereas typically developing participants demonstrate an “eye-bias” or a robust preference to focus on another person's eyes (Birmingham, Bischof, & Kingston, 2008; Foulsham et al., 2010; Klin et al., 2002; Ro, Russell, & Navie, 2001), this does not appear to be the case in ASD (Jones & Klin, 2013; Kikuchi et al., 2009; Klin et al. 2002; Pelphry et al, 2002; Spezio et al., 2007). Thus, minimizing the role of gaze-selection may occlude orienting to gaze deficits in ASD, given that gaze-selection and gaze-following are arguably associated behaviours within the context of social attention (Birmingham & Kingstone, 2009).

1.2.7. Present study

The central aim of this dissertation was to increase the ecological validity of the computerized attention tasks designed to assess selective attention to gaze cues. The flicker task was chosen for several reasons. First, it allowed me to isolate and operationalize attention to specific scene areas indicative of either social or non-social selection or following behaviour. Second, I wished to explore issues raised from previous research on gaze-cueing (i.e. Freeth et al., 2010; Langton et al., 2006; Sheth et al., 2011). In particular, I wished to compare gaze-following with another non-social directional cue (i.e. an arrow) to expand upon previous findings and discover whether previous findings of spontaneous following are specific to a social cue.

The central research question was: **Do adults with typical development prioritize shifting/orienting attention in response to eye-gaze relative to attending to anon-social cue?** The secondary question was: **Do individuals with ASD demonstrate different attentional biases for following social vs. non-social directional cues?**

Testing of these questions was accomplished by introducing a novel manipulation within a flicker task - competition between eye-gaze and arrow cues within realistic scenes. Gaze and arrow cues competed for attention within a series of five flicker tasks. First attentional biases in TD adults were examined. Traits of ASD were measured by having typical participants complete a questionnaire designed to detect characteristics of ASD in the normal population (i.e. the Autism Spectrum Questionnaire, AQ; (Baron-Cohen et al., 2001), and these ratings were compared with orienting to gaze performance. Several facets of the attention to gaze cues were characterized: the strength of the orienting to gaze response in comparison with non-social orienting (in response to arrows), the time course of the response and it's susceptibility to the effects of visual salience. The task was then piloted on participants with a clinical diagnosis of ASD.

1.2.7.1. Specific hypotheses

Experiment 1 measured gaze and arrow following in TD adults in order examine whether either gaze or arrow cues are prioritized (i.e., selected and used to orient attention toward a target). Singular gaze or arrow cues were centrally presented within a flicker task. Participant's attention was measured for changes to cued vs. non-cued objects within the scene to see if previous findings of spontaneous gaze-following within flicker tasks (Langton et al., 2006) are unique to social cues. It was hypothesized that when presented alone, arrows and eye-gaze would elicit equal following.

In Experiment 2, the emphasis on selection was increased by introducing competition (i.e. simultaneously presented gaze and arrow cues indicating opposite locations/directions), thereby forcing TD adult participants to choose between two cues. In addition, both components of attention (selection and following) were explicitly measured. It was hypothesized that when demands on selection are increased, participants are more likely to reveal a priority to follow eyes over arrows.

In Experiment 3, demands on selection were increased by including time limits were introduced - finite viewing times forced TD adult participants to make decisions very quickly. The aim was to see if biases reveal themselves under time pressure and also to explore any temporal relationships between selection and following. It was predicted that selection of eyes would occur earlier than gaze-following, based upon the hypothesis that gaze-selection precedes gaze-following (Baldwin, 1995).

In Experiment 4, the visual salience of arrows was decreased in order to examine the effects of visual saliency on attention in TD adult participants. Based upon indications that gaze-following is a highly species relevant behavior (Emery, 2000), it was predicted that eyes would be followed even if they are non-salient. However, it was hypothesized that saliency would influence arrow following (arrows that are more salient would be followed more often).

In Experiment 5, social attention was examined in adolescents/young adults with ASD, as compared with TD controls. Based upon findings from initial experiments, it was predicted that participants with ASD would demonstrate reduced early selection of gaze and reduced gaze-following as compared to their TD peers.

With regards to the two central research questions that guided the progression of experiments, it was predicted that when shown gaze and arrow cues in real-world scenes, TD participants would demonstrate a preferential bias to follow eye-gaze but not arrows. Further, it was predicted that individuals with ASD would demonstrate diminished attention to gaze cues relative to TD comparison participants.

2. Experiment 1

This experiment measured gaze and arrow following in TD adults in order to test whether either gaze or arrow cues are prioritized (i.e., selected and used to orient attention toward a target). Previous flicker tasks measuring orienting to gaze in participants with TD and ASD (i.e. Freeth, Ropar, Chapman & Mitchell, 2010; Langton, O'Donnell, Riby & Ballantyne, 2006; Sheth et al., 2011) have presented only a singular gaze cue within a scene, making it unclear whether spontaneous cue-following is specific to gaze or whether any directional cue would elicit a spontaneous orienting response. Orienting to gaze and arrow cues were compared within a flicker task; participants viewed scenes containing either an arrow or eye-gaze cue that did or did not indicate the location of the change. To control for equivalence of cues in terms of visual properties, artificial arrows (inserted using Photoshop) where placed in the same location (and making them roughly the same size) as a person's face region in the arrow cue version of a scene. In order to control for difficulty of change detection across cue types, a between subjects design was used. Four versions of each scene were created (valid/invalid x gaze/arrow cue) and each was viewed by a different participant. The data was then collapsed across participants for analysis. The Autism Quotient (AQ), a screener for ASD traits in the general population (Baron-Cohen et al., 2001), was used to determine whether gaze/arrow following performance was related to ASD traits. Based upon previous findings of orienting to gaze within photographs, spontaneous orienting to gaze as indicated by faster detection of validly cued changes over invalidity cued changes was anticipated.

Based upon the hypothesis that singular cues are not effective at uncovering biases for social information, it was predicted that the arrow and gaze cueing of comparable magnitude would be observed. Similarly, it was anticipated that TD participants with high AQ scores would demonstrate equivalent gaze and arrow following.

2.1. Method

2.1.1. Participants

Ninety-two undergraduate students (76% female, mean age = 20.1 years) from Simon Fraser University (SFU) participated in Experiment 1. Data from one participant was excluded from the final analysis because they had overall low accuracy (number of errors was 3 standard deviations above the mean error rate). The overall mean of AQ scores was 17.11 with an AQ mean of 14.86 for males and 17.81 for females. All participants had normal or corrected-to-normal vision and did not self-identify as having untreated Attention Deficit Hyperactivity Disorder (ADHD). Prior to this experiment, pilot testing was run on 22 participants to work out programming bugs and irregularities with the scenes. As in all experiments in this dissertation, participants signed up to the study in order to receive course credit for their introductory psychology course. All participants participated in only one experiment.

2.1.2. General procedure

Details of the study were described to participants and written informed consent was obtained. The study received approval from SFU's department of research ethics. Participants then filled out a brief demographics survey form (e.g. age, sex, corrected vision) and the AQ questionnaire. They then completed the computer flicker task. Following completion of the flicker task, participants were given a debriefing form and allotted course credit for their participation.

2.1.3. Measures

All participants completed the Autism Spectrum Quotient questionnaire or AQ (Baron-Cohen et al., 2001). This 50 item self-report measure assesses autistic traits along five domains: social skills, attention switching, attention to detail, communication, and imagination with two validated factors: "Social Interaction" and "Attention to Detail" (Hoekstra, Bartels, Cath, & Boomsma, 2008). The AQ has proven validity and reliability for assessing individual differences in autistic trait levels in general population (e.g. (Baron-Cohen et al., 2001; Kurita, Koyama, & Osada, 2005). Higher scores indicate higher autistic traits. Scores 26 or higher indicate significant levels of self-identified ASD-like traits (Baron-Cohen et al., 2001). Please see Appendix A for a copy of the AQ.

2.1.4. Apparatus and stimuli

Stimuli consisted of colour digital photos that were displayed on a 10” x 16” LCD monitor. E-prime 2.0 software was used for stimulus display. The software was run on a Dell Latitude Z600 laptop computer. Image size was 10” x 16” which corresponded to 20.56 º x 32.34 º at a viewing distance of approximately 70 cm. Image resolution was 1250 x 940 pixels.

There were 16 experimental scenes each containing either a person with averted eyes or an arrow in the centre of the scene. Gaze and arrow cues were non-competing and there was only one directional cue in each scene. For each original photo, a changed image was made using Adobe Photoshop. Changes consisted of removal of an object, change to an object, or an object colour change. Changes in experimental scenes were either 50% *valid*: changes where the eyes are looking, changes where the arrow is pointing, or 50% *invalid*: changes in the opposite direction from where the eyes or arrow is pointing. Six trials contained a cue direction to the right that was valid and a left invalid gaze cue valid right gaze, 6 scenes contained left valid and right invalid cues, 3 scenes contained forward/down valid cues and upwards invalid cues. See Figure 2.1 for examples of experimental scenes. In addition to experimental scenes, the task included 4 practice scenes (one valid arrow, one valid gaze, and 2 filler scenes) and 6 filler scenes (see Figure 2.2 for an example of a filler change). Filler changes were included so that it would be less evident to participants that the study was measuring gaze and arrow following.

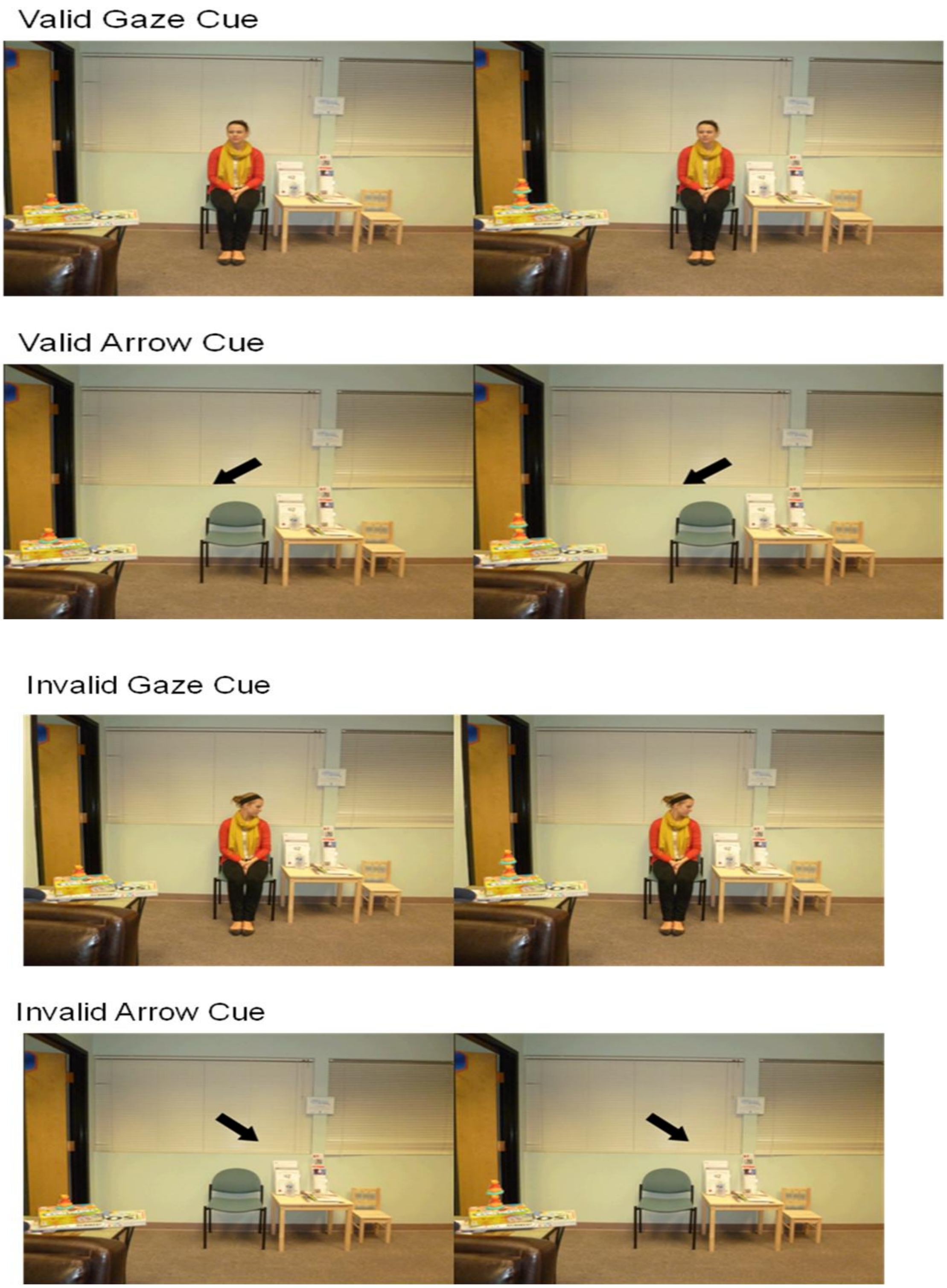


Figure 2.1. Examples of experimental scenes for experiment 1 where a gaze or arrow cue was either valid or invalid, with change being the appearance of another toy in the lower left hand area of the photograph.

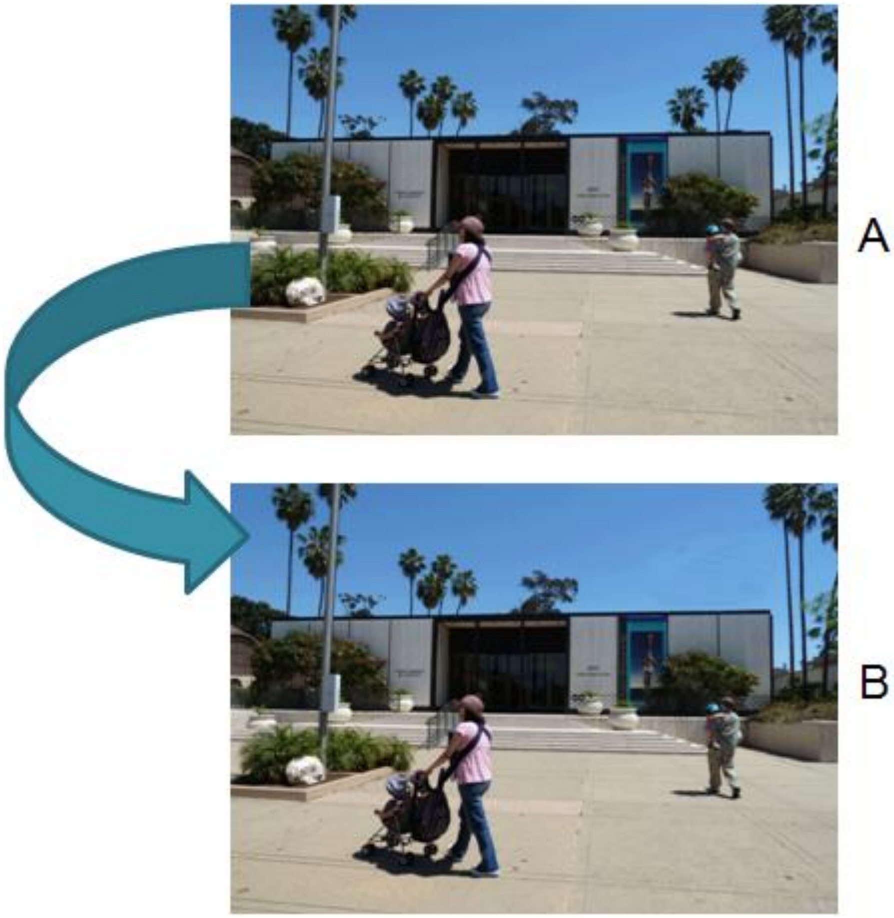


Figure 2.2. Example of one of eight filler scene used in experiments 1 – 5, where the change is the disappearance of palm trees on the upper right side of the building.

2.1.5. Design

A between subjects repeated measures design was used. Within each scene, changes were indicated by a gaze or arrow cue (cue type) that was either valid or invalid (validity). Cue type and validity for each scene were counter-balanced across participants to create 4 versions of the experiment (see Table 2.1 for details of the experimental design). For example, one participant would view a scene with a valid arrow, another would view that same scene with a valid gaze cue, another would view that same scene with an invalid arrow, and yet another participant would view that scene with an invalid gaze cue. Changes remained identical within each scene. In this manner, difficulty of finding a particular change and any variability in visual saliency of a change was controlled. Thus, each participant viewed one of 4 versions of the experimental scenes. Data was collapsed across participants for analysis. The main dependent variable of interest was time elapsed before changes were detected (RT). Accuracy of change detection was also measured using the region on the grid wherein the participant had indicated the change and comparing this with the region on the grid that contained the change. Each participant viewed a total of 26 scenes including: 4 practice trials, 6 filler changes, 4 valid gaze cues, 4 invalid gaze cues, 4 valid arrow cues, and 4 invalid arrow cues. Trials were presented in random order (generated by E-prime). Overall, both gaze and arrow cues were non-predictive and accurately indicated the location of the change on only 18% of trials.

Table 2.1. *An illustration of how cue type and validity were balanced across scenes and participants. Each participant viewed one out of the four versions of experiment 1 and viewed a total of 16 experimental scenes.*

	Scene 1	**Scene 2**	**Scene 3**	**Scene 4**
Version 1	Valid gaze cue	Valid arrow cue	Invalid gaze cue	Invalid arrow cue
Version 2	Valid arrow cue	Invalid gaze cue	Invalid arrow cue	Valid gaze cue
Version 3	Invalid gaze cue	Invalid arrow cue	Valid gaze cue	Valid arrow cue
Version 4	Invalid arrow cue	Valid gaze cue	Valid arrow cue	Invalid gaze cue

2.1.6. *Procedure*

The flicker task commenced with the display of an instruction with the following message: “You will see a flickering picture. Try to spot a change in the picture as fast as you can. Indicate that you have found a change by pressing the SPACE bar. Then use the mouse to click on the screen area where you saw the change. Press the SPACE to continue.” Each trial began with a 100-ms presentation of a blank screen, then the original scene was presented for 500-ms. After another 100-ms presentation of a blank grey screen, the modified version of the scene was displayed for 500-ms. These slightly longer time intervals (Freeth, Chapman, et al., 2010; Freeth, Ropar, et al., 2010; Langton et al., 2006) were chosen because they allowed a rate of flickering that was not averse to viewers (as determined in pilot testing). The sequence was repeated until the participant indicated that they had detected the change by pressing the space-bar (RT measure). Once the space-bar was pressed, the original scene with a 9 part grid overlay was displayed. Participants used the mouse to click on the grid area where they had spotted the change (accuracy measure). A screen then prompted the participant to start the next trial by pressing on the spacebar. See Figure 2.3 for an illustration of the trial sequence. Prior to performing the flicker task, the participants were given instructions both verbally and on the computer screen. The task began when the participant pressed the space bar. Participants first completed 4 practice trials. Feedback was given regarding performance on practice trials: “Oops. You were incorrect. Push the SPACE bar to continue” or “You found the change! Push the SPACE bar to continue.” Feedback was given regarding performance on practice trials to ensure maximum understanding of the task demands. Experimental instructions were then displayed: “Now that we've practiced, let's try some more. Remember: *Don't hit the space bar until you see the change* *Make sure to click inside the correct box*”. A total of 16 experimental trials and 6 filler changes, were then completed.

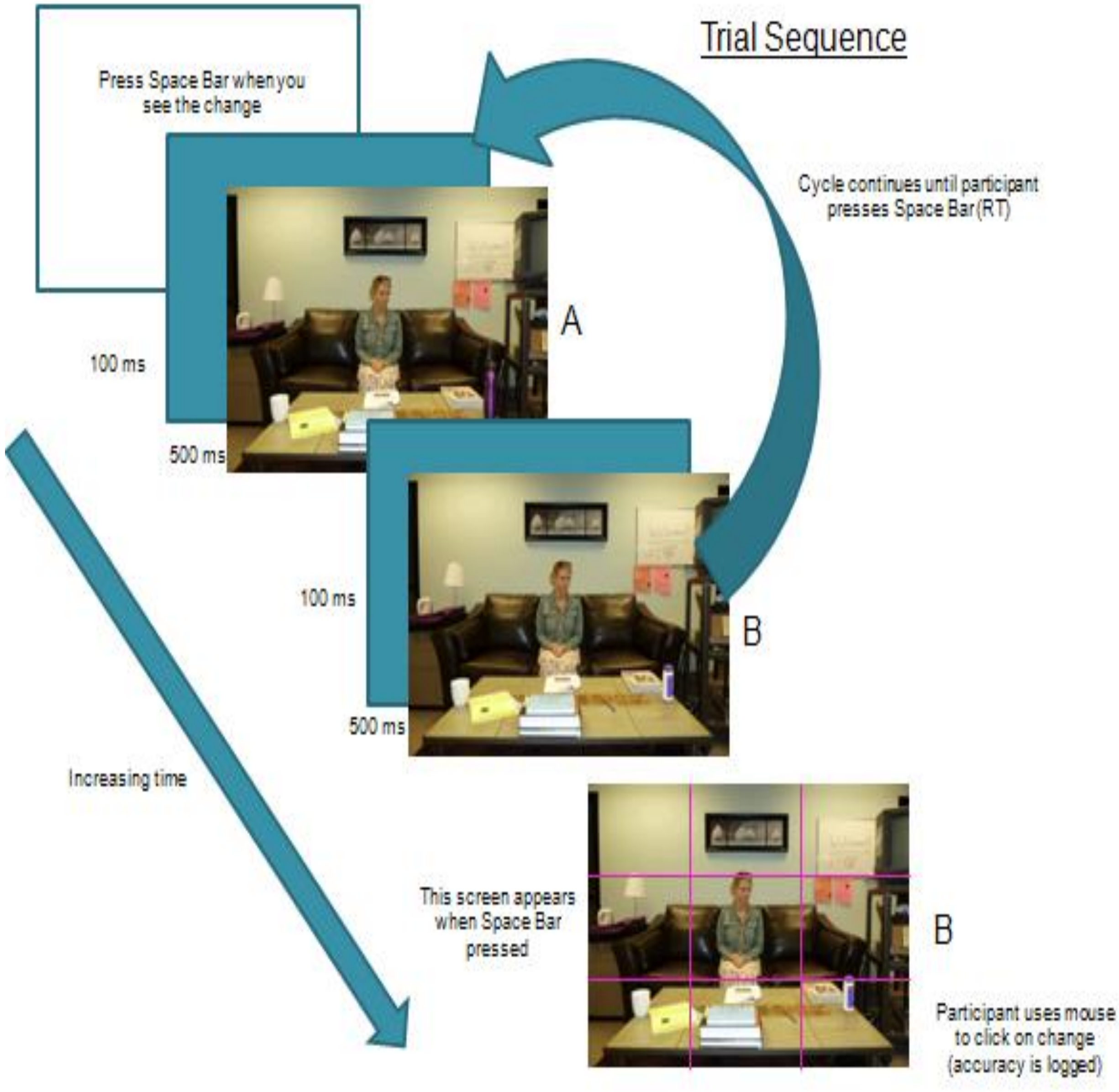


Figure 2.3. Example of the sequence of events during a trial in experiment 1.

2.2. Results

Twenty-three participants completed each version (1 through 4) for a total of 92 participants. Prior to analysis, data preparation involved removal of all inaccurate trials where the participant failed to accurately locate the change. Inaccurate trials made up 4% of experimental trials. Analyses were run on the remaining 96% of data. Experimental trials were then collapsed across participants and experimental versions into 4 trial type categories (valid gaze, invalid gaze, valid arrow, invalid arrow). For each trial type, means (M) and standard deviations (SD) were calculated. Outlying RTs were identified (data points lying 3 SDs above the M) and removed from the data set. Outliers comprised approximately 4% of the data overall: 2.9% for valid gaze trials, 3.5% for invalid gaze trials, 3.6% for valid arrow trials, and 3% for invalid arrow trials.

The 4 counter-balanced versions of the experiment were collapsed across participants. As such, data was treated as within subjects. The planned repeated-measures ANOVA on mean RTs with cue type (arrow vs. gaze) and validity (valid vs. invalid) was not run as data did not meet statistical assumptions for this test. Assumption testing revealed that the distribution of RTs scores was non-normal (i.e. Shapiro-Wilk tests run on DVs yielded p values below 0.05, the distribution was skewed to the left indicating faster RTs). Thus, non-parametric equivalents of planned pair-wise comparisons were run. Bonferroni corrections were made and the alpha-value was lowered to 0.01. Wilcoxon Signed Ranks Tests revealed significant cueing effects for both gaze cues (Z = -5.011, p = 0.000) and arrows (Z = -6.00, p = .000). In particular, on gaze cued trials, changes were detected significantly faster on valid trials (M = 4646.54 ms, SD = 2189.22 ms) as compared with invalid trials (M = 6385.75 ms, SD = 2558.62 ms). This was also the case for arrow cued trials where changes were detected significantly faster on valid trials (M =4237.17 ms, SD = 1849.87 ms) as compared with invalid trials (M = 6865.01 ms, SD = 3616.77 ms). Cue validity did not have a differential effect on gaze vs. arrows as trial means were not significantly different between valid trials (Z = -1.49, p = .134) or invalid trials (Z = -1.17, p = .907). Finally, when standard cueing effects were calculated (means differences between valid and invalid trials), no statistically significant difference was found between the magnitude of the cueing effect for gaze vs. arrows (Z = -1.35, p = .175). Thus, it appears that participants followed gaze and arrow cues equivalently. See Figure 2.4 for a visual depiction of results from experiment 1.

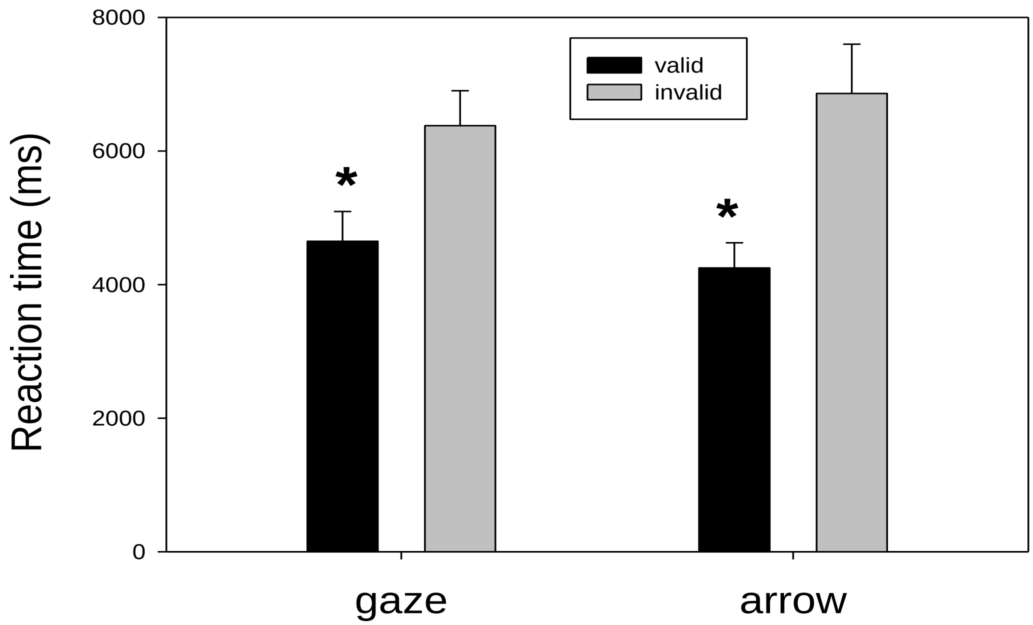


Figure 2.4. Mean response times (with bars denoting 95% confidence intervals) for valid and invalid gaze and arrow cues in experiment 1.* indicates significantly faster response time for valid cues, $p < 0.05$.

2.2.1. AQ results

Non-parametric correlations were run on AQ scores and task performance (with Bonferroni corrections to correct for multiple comparisons). A significant positive correlation was found between RTs on valid gaze trials and AQ scores, r_s (91) = .30, p = .004, indicating that higher AQ scores were associated with slower detection of changes indicated by a valid gaze cue. See Figure 2.5 for a graph of this correlation. The AQ "Social Interaction" subdomain in which higher scores denote more social difficulties and the "Attention to Detail" subdomain in which higher scores indicate greater attention to detail (Hoekstra et al., 2008) were entered into the correlation analysis. A significant correlation between the Social Interaction subdomain score and slower performance for scenes with valid gaze, r_s (91) = 0.30, p = .012 was found. Thus, individuals who self-identified as having more social difficulties were slower to find changes indicated by gaze. There were no other significant correlations between AQ scores and task performance.

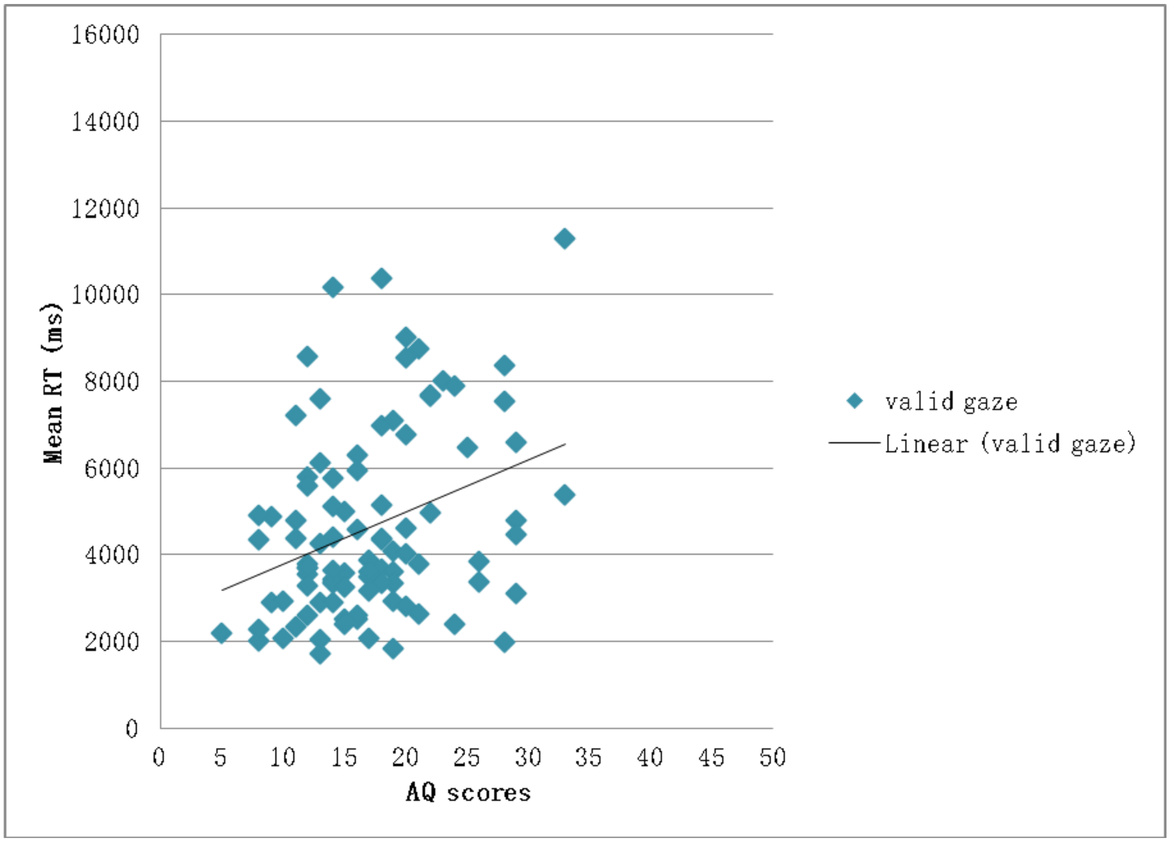


Figure 2.5. The distribution of mean reaction time scores for scenes with a valid gaze cue as a function of AQ, where the trendline represents a significant positive correlation, $r_s(91)= .30$, p = .004.

Eleven participants scored 26 or higher on the AQ and therefore self-identified as having a significant number of traits in common with persons with ASD. These participants were classified as “high scorers”. Wilcoxon Signed Ranks Tests revealed significant cueing effects for arrow cues (Z = -1.96, *p* = 0.050) but not for gaze cues (Z = -1.60, *p* = .110) in these high scoring individuals. In particular, on arrow cued trials, high scorers detected changes significantly faster on valid trials (M = 4330 ms, SD = 1633 ms) vs. invalid trials (M = 6479 ms, SD = 1993 ms). However, on gaze cued trials, the difference between mean for valid trials (M = 5524 ms, SD = 2724 ms) was not significantly faster than the mean on invalid trials (M = 8037 ms, SD = 3682 ms), perhaps due to larger variability in mean response times for this condition. There was more variability in the invalid gaze cued scores of the high AQ group (SD = 3682 ms) over the normal AQ group (SD = 2558 ms), which could explain why there was no gaze-cueing validity effect found for the high AQ group. Overall, it appears that the high AQ scorers did not follow gaze cues. See Figure 2.6 for a graph that depicts the performance of the high scorers.

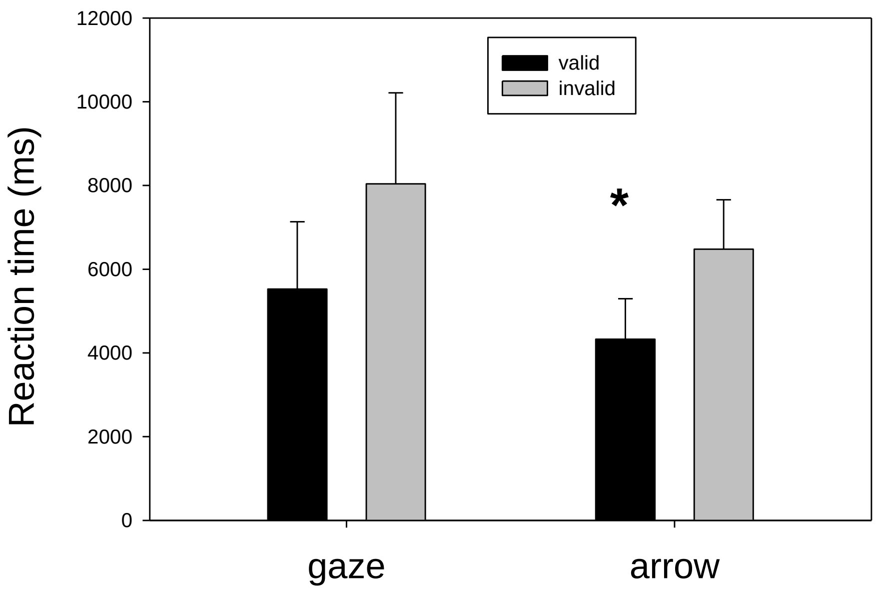


Figure 2.6. Mean response times (+ 95% confidence intervals) of participants with high AQ scores for valid and invalid gaze and arrow cues in experiment 1.* indicates significantly faster response time for valid cues, $p < 0.05$.

2.3. Discussion

The aim of Experiment 1 was to determine how eye gaze cues versus a non-social directional cue (i.e. an arrow) direct visual attention within real-world scenes. This was done by comparing orienting to gaze and arrows using a flicker task. In this study, gaze and arrow following (as indexed by speed of detection for cued changes) were compared in ninety-two undergraduate students. Although gaze and arrow cues have been compared within the context of the spatial cueing paradigm (Friesen et al., 2004;

Hommel et al., 2001; Ristic et al., 2002; Ristic, Wright, & Kingstone, 2007; Tipples, 2002, 2008), this is the first study to compare the cues using photographs of real-world scenes.

Both gaze and arrows produced overall significant cueing effects. Cues were followed spontaneously despite the fact that they did not reliably indicate the location of the change. These findings confirm previous results of automatic orienting in response to eyes (Friesen & Kingstone, 1998) and arrows (Hommel et al., 2001). Gaze and arrow cues produced cueing effects of equal magnitude which supports the prediction that singular cues do not reveal social biases. This finding is consistent with previous findings of indistinguishable behavioural effects using a singular cue within the cueing paradigm (Hommel et al., 2001; Kuhn & Benson, 2007; Kuhn & Kingstone, 2009; Nummenmaa & Hietanen, 2009; Tipples, 2008). Possibly, in presenting singular and central gaze or arrow cues, the current task did not force participants to reveal their attentional priorities and cues were followed equally.

The secondary aim of Experiment 1 was to explore potential associations between cue following and autistic traits. Contrary to predictions, diminished orienting to gaze was found in typically developing participants with higher levels of self-identified autistic traits. A moderate positive correlation was found between speed of orienting to gaze and AQ scores which indicates that participants with a greater number of ASD traits were slower to follow eye gaze towards areas of change. Also, when participants were divided into "high scoring" and "average scoring" groups based upon AQ scores, high scoring individuals did not demonstrate a significant cueing effect for gaze. They did, however, demonstrate a significant cueing effect for arrows. Thus, participants with ASD like traits were more inclined to follow arrows than eyes. These findings contradict previous findings of intact orienting to gaze in participants with ASD (Freeth, Ropar, et al., 2010; Sheth et al., 2011) but fit with findings of lack of preferentially sensitivity to gaze over arrows in this population (Rombough & Iarocci, 2013; Senju et al., 2004; Vlamings et al., 2005). However, AQ findings must be interpreted with caution. First, the threshold for "high AQ" scoring was low (i.e. 26) relative to people who have diagnoses of ASD (who typically score 35 or higher on the AQ). Second, lack of gaze-cueing in the high scoring group may have been an artifact of more variability on invalid gaze-cued trials and therefore may not indicate a meaningful finding. Overall, results would need to be replicated with a high scoring ASD group (35 or higher on the AQ).

3. Experiment 2

In Experiment 1, gaze and arrow cues appeared separately and were equally predictive of where the target change occurred and thus, participants followed each in turn. In Experiment 2, the goal was to examine how participants prioritize or select eye-gaze and arrow cues that appeared simultaneously and competed for attention. Arrow cues were naturally occurring (e.g. on street signs) yet efforts were made to ensure that arrows were salient cues since arrows are typically ignored in naturalistic scenes (Birmingham et al., 2009a; Birmingham, Bischof, & Kingstone, 2009b). The size, positioning, and luminance of arrows were varied in order to increase the visual salience of arrows in half of the scenes. Attention for changes to objects indicated by either eye-gaze or arrows was then compared with attention for control changes. This experiment also explicitly measured both selection and following (e.g. attention for changes to the eyes and attention for changes to objects indicated by a person within the scene's eye-gaze direction). As in Experiment 1, Experiment 2 also examined the relations between ASD-like traits and task performance.

Several predictions were made. First, based on previous studies that have shown that faces attract attention in a robust manner (Langton, Law, Burton, & Schweinberger, 2008; Theeuwes & Van, 2006) but that arrows are not selected in real-world scenes (Birmingham et al., 2009a), it was hypothesized that the selection of eyes would be prioritized over arrows cues. Accordingly, it was predicted that changes to eyes would be detected quickly (i.e. faster than control changes) but that changes to arrows would not be detected faster than control changes. Second, it was hypothesized that spontaneous orienting of attention would be observed for both arrows and gaze, based upon findings from Experiment 1. However, given that cueing is likely dependent upon selection, faster gaze-following relative to arrow-following was expected. Third, it was predicted that higher AQ scores (associated with more ASD traits) would positively correlate with less spontaneous gaze cueing (slower detection of changes in gaze cued locations) and abnormal selection of gaze (slower detection of changes to eyes).

3.1. Method

3.1.1. Participants

Twenty-two undergraduate students (75% female, mean age = 24.5 years) from Simon Fraser University (SFU) participated in Experiment 2. Data from one participant was excluded from the final analysis because of low accuracy (errors on 25% of trials). The overall mean of AQ scores was 15.71 with an AQ mean of 15.16 for males and 15.93 for females, well within average for the general population (Baron-Cohen et al., 2001).

Prior to Experiment 2 described below, twenty-one undergraduates from SFU (50% female, mean age = 19.8 years) participated in a pilot experiment to norm change detection difficulty with the aim of balancing difficulty evenly across experimental conditions. Participants in the pilot experiment viewed the stimuli with obscured directional cues (see Figure 3.2 for an illustration) and rated the difficulty of each scene change. Mean AQ score for this group was 16.35 overall with a mean of 16.7 for males and 16 for females.

All participants were naïve to the purpose of the experiment. They had normal or corrected-to-normal vision and did not self-identify as having untreated ADHD.

3.1.2. General procedure

Details of the study were described to participants and written informed consent was obtained. Participants then filled out a brief demographics survey form (e.g. age, sex, vision) and the AQ questionnaire. They then completed the computer flicker task. Following completion of the flicker task, participants were given a debriefing form and allotted course credit for their participation.

3.1.3. Apparatus and Stimuli

As in Experiment 1, stimuli consisted of colour digital photos that were displayed on a 10” x 16” LCD monitor. E-prime 2.0 software was used for stimulus display. The software was run on a Dell Latitude Z600 laptop computer. Image size was 10” x16” which corresponded to 20.56 º x 32.34 º at a viewing distance of approximately 70 cm. Image resolution was 1250 x 940 pixels.

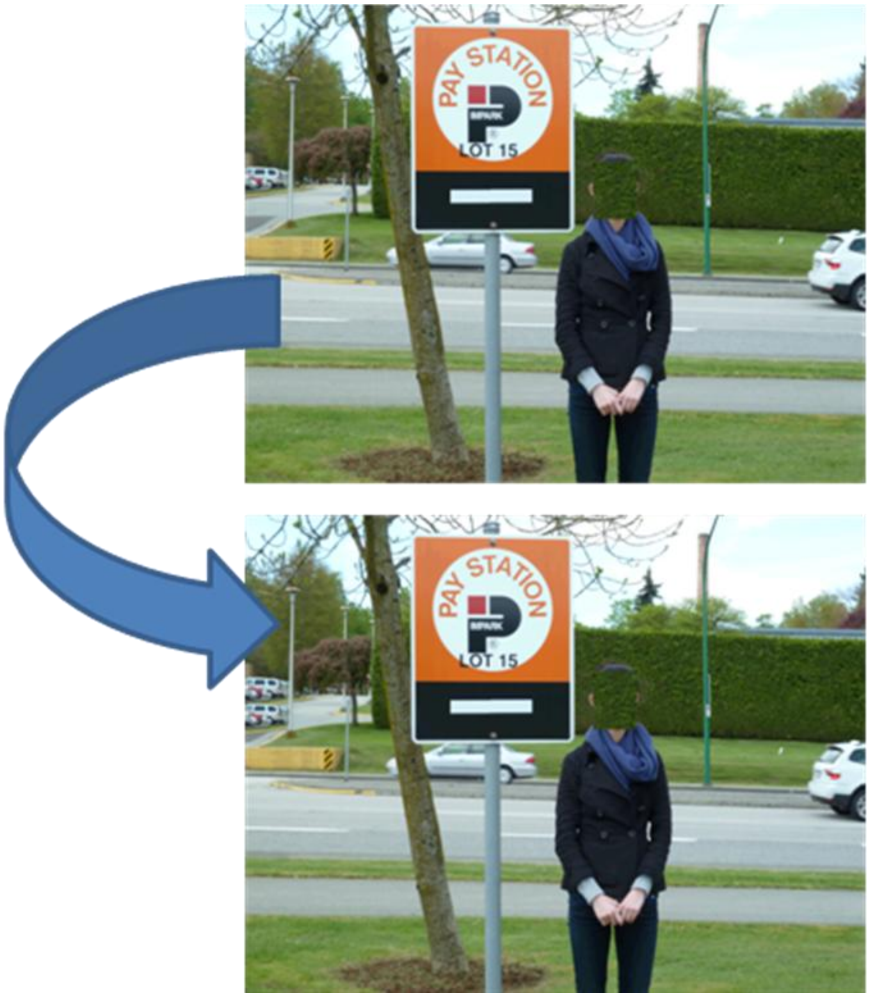
Each of the 41 experimental scenes contained a person with averted eyes and an arrow that pointed in a direction other than the one indicated by gaze. Thus, gaze and arrow cues were competing. The same 8 filler scenes used in Experiment 1 were shown. For each original photo, a changed image was made using Adobe Photoshop. Changes consisted of removal of an object, addition of an object, replacing one object with another or an object colour change. Changes in experimental scenes were either: 1. *selection changes* including eye changes (changes to the eye region of a person in the scene) and arrow changes (changes to arrows in the scene), 2. *following changes* including gaze-cued changes (changes to objects referenced by gaze direction) and arrow-cued changes (changes to objects referenced by arrow direction) or 3. *control changes* (changes to object not cued by gaze or arrows). Control changes were similar to changes that would have been seen in a classic flicker task and were included to provide a baseline of change detection that was independent from directional cues. Attempts were made to counterbalance the location (i.e. central vs. peripheral, in front vs. behind) of the arrows relative to people within the scenes. See Figure 3.1 for an example of each change type. Refer to Appendix B for more samples of stimuli. Additional changes made using Photoshop included the highlighting of half of the arrows in order to increase arrow saliency.

Figure 3.1*.* Examples of each type of experimental change for experiments 2 -5.

3.1.4. Norming of change difficulty

Norming was completed to control for change difficulty across scenes and change types. Prior to Experiment 2, a variety of scenes were normed on twenty-one undergraduate students who viewed the stimuli with obscured gaze and arrow cues – hereafter referred to as norming scenes (see Figure 3.2 for an example). This was done in order to gauge the difficulty of each scene change independent of cueing effects. Mean response times for each type of norming scene were obtained. Scenes with approximately equivalent norming means (i.e. equal level of change difficulty) were selected for each trial type including: arrow-cued changes, gaze-cued changes and control changes. Norming was not possible for eye changes or arrow changes because covering over the directional cue would obscure the change.

Final experimental scenes consisted of 8 gaze-cued scenes (mean norming RT = 10041.46 ms, SD = 6223.40 ms), 8 arrow-cued scenes (mean norming RT = 9978.26 ms, SD = 7529.60 ms), and 16 control scenes (mean norming RT = 10032.88 ms, SD = 7816.30) with approximately equivalent mean RTs. Two repeated measures 3-way ANOVAs with scene type (gaze-cued, arrow-cued, control) a within subject factor confirmed that there were no statistically significant differences between the norming means, F (2, 29) = .000, p < .001, or standard deviations, F (2, 29) = .564, p < .001, for each experimental change type (see Figure 3.3 for graphic representation of this data).



A

B

Figure 3.2. An example of a norming scene with cues obscured for the purposes of controlling for change difficulty across experimental scene types.

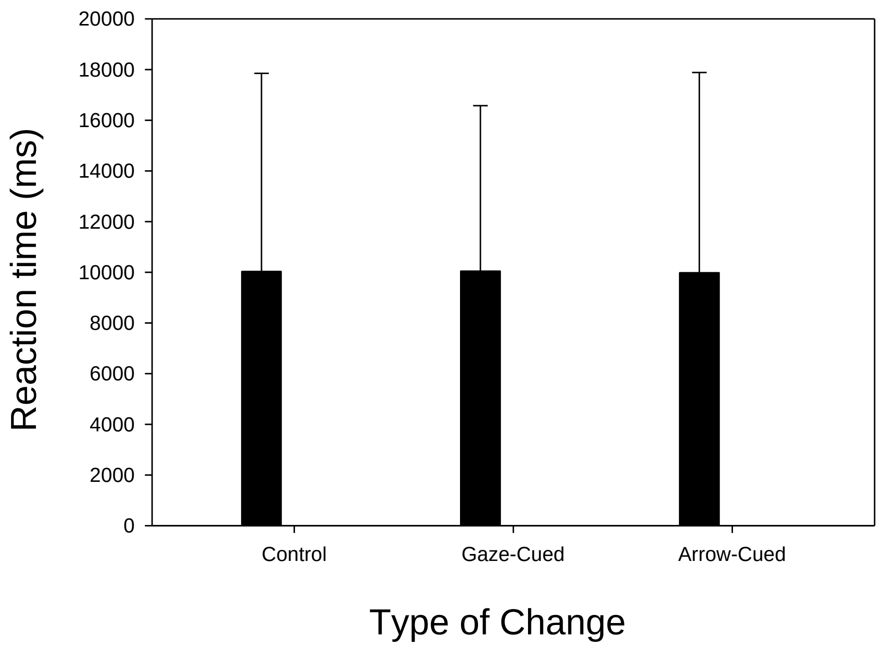


Figure 3.3. Equivalence of mean reaction times (+ 95% confidence intervals) for norming control, gaze-cued, and arrow-cued trials.

3.1.5. Design

A within subjects repeated measures design was used. Recall that there were five types of experimental changes: 2 selective attention changes (eye changes, arrow changes), 2 following changes (gaze-cued, arrow-cued) and 1 control change. The main dependent variable of interest was time elapsed before changes were detected (RT). Accuracy was also measured by logging the screen area indicated by the participants and comparing this with the screen area containing the change. Participants viewed a total of 51 scenes including: 4 practice trials (1 arrow-cued, 1 gaze-cued, and 2 filler scenes), 6 filler changes, 3 eye changes, 6 arrow changes, 8 gaze-cued changes, 8 arrow-cued changes, and 16 control changes. All scenes contained a change but participants were not told that this was the case. Both gaze and arrow cues were non-predictive and accurately indicated the location of the change on only 15% of trials.

3.1.6. Procedure

The sequence of events during a trial was similar to Experiment 1 with the exception of slightly longer time intervals (Please see Figure 3.4 for an illustration). Longer time intervals were chosen because some participants complained that the speed of the flashing scenes for Experiment 1 was aversive. Each trial began with a 750 ms presentation of the original version of a scene, followed by a 150 ms blank grey screen, presentation of the modified scene for 750 ms, and then the 150 ms blank. The sequence was repeated until the participant indicated that they had detected the change by pressing the space-bar and provided a RT measure. Once the space-bar was pressed, the original scene with a 9 part grid overlay was displayed. Participants used the mouse to click on the grid area where they had spotted the change, thus providing an index of accuracy. A screen then prompted commencement of the next trial by pressing on the spacebar. See Figure 3.4 for an illustration of the trial sequence.

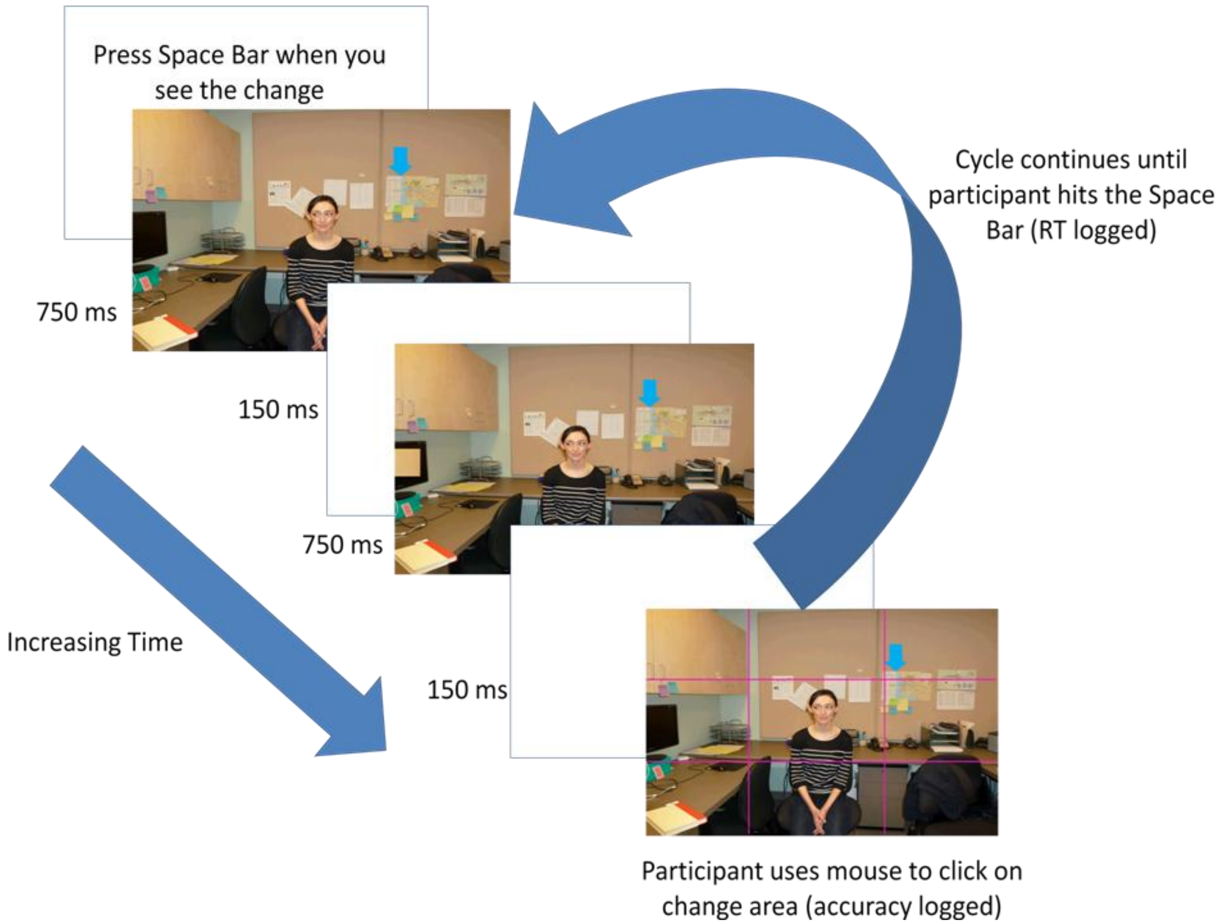


Figure 3.4. Example of the sequence of events during a trial in experiment 2.

3.2. Results

Prior to analysis, data preparation involved removal of inaccurate trials and outliers. Analyses were conducted on correct trials only (trials wherein the participant accurately located the change). In general, accuracy was high (96.3% correct) with each subject making an average of 1.8 errors. One scene was removed from the final analysis because it produced more errors than other trials (12 errors; more than 3 SD above the mean number of errors). Data from one participant was removed due to low accuracy (i.e. errors on 36% of trials; more than 3 SDs above the mean number of errors). Outlying data points that fell 3 standard deviations above the mean RT for that trial type were removed prior to analysis and comprised a low number of trials (average of 0.36 outliers per scene).

A repeated-measures ANOVA was run on mean RTs with trial type (eye change, arrow change, gaze-cued change, arrow-cued change, control change) as within subjects factor. Prior to these analyses, assumption tests confirmed normality (Shapiro-Wilk tests on the dependent variables were significant). A significant main effect for trial type was found, F (4, 80) = 15.12, p < .001. Planned paired-samples t-tests (with Bonferroni corrected alpha values) indicated that this effect was driven by faster mean RTs for detecting eye changes over other types of changes. In particular, eye changes were detected faster than arrow changes, t (20) = 4.95, p = .001, and control changes, t (20) = -11.67, p = .001. Contrary to predictions, no significant following effects were detected: mean RTs for control changes did not differ significantly from RTs for gaze-cued changes, t (20) = -.008, p = .251, or arrow-cued changes, t (20) = 1.18, p = .994. Further, there were no indications that gaze-following occurred more than arrow-following; mean RTs for gaze and arrow-cued changes were not significantly different, t (20) = -.95, p = .351 (there was no difference for highlighted vs. un-highlighted arrows). Eye changes were detected significantly faster than gaze-cued changes, t (20) = -7.34, p < .001. See Figure 3.5 for a graph of findings from Experiment 2.

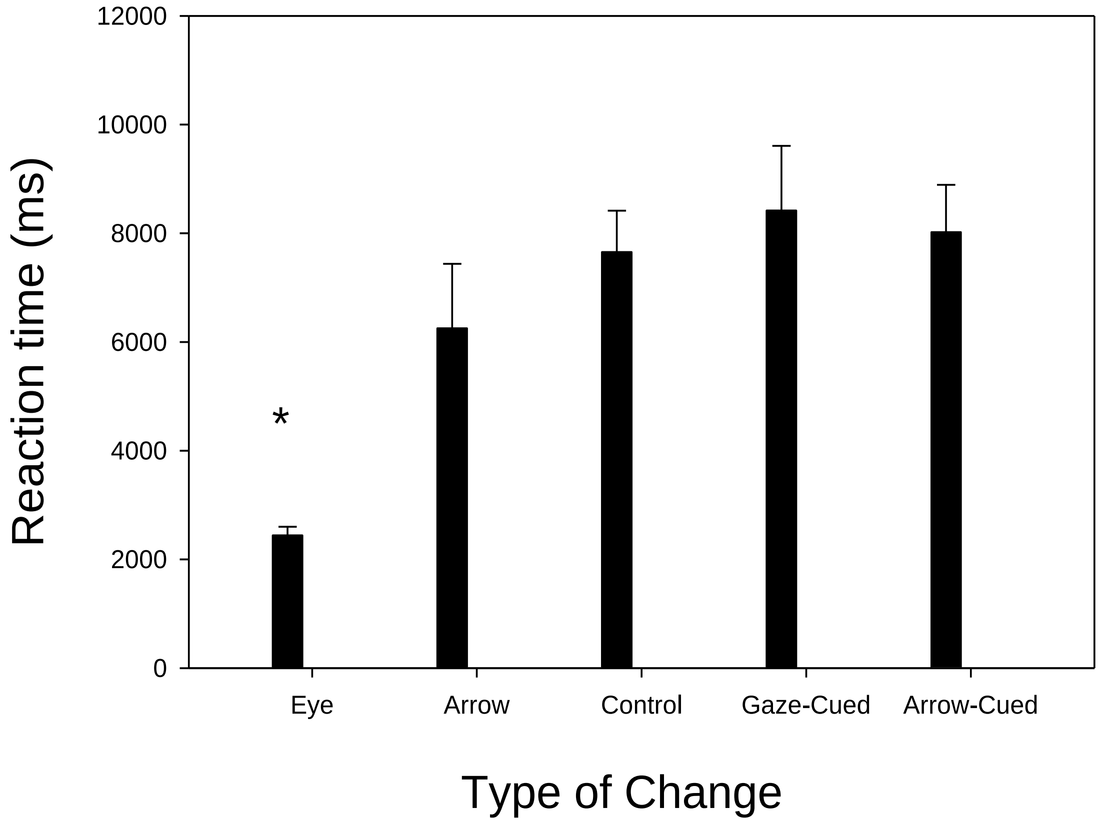


Figure 3.5. Mean reaction time performance in milliseconds (ms) (+ 95% confidence intervals) for each experimental trial type in experiment 2. * indicates a statistically significant difference at p < .001.

Several participants provided feedback during debriefing that they had initially attended to gaze-cues but switched to an alternate search strategy (e.g. searching in a circle for the change) after they determined that gaze-cues were not predictive of the change location. In order to examine whether gaze-cueing occurred early on in the task, analyses on the first five trials were conducted. As trials were presented in random order, for those participants who did not view a particular change type in the first 5 trials, The RT for their first trial of that type was inserted into the empty cell. For example, if a participant did not view a gaze-cued change in the first five trials but viewed this change type on trial number 17, their RT for trial 17 was inserted into the empty data cell. A repeated measures ANOVA on mean RTs from the first five trials with trial type (eye, arrow, gaze-cued, arrow-cued, control) as a within subjects factors revealed a significant main effect for trial type, F (4, 80) = 3.48, p = .011. Planned paired sample t-tests (with Bonferonni corrected alpha values) confirmed that in the first 5 trials, gaze-cued changes were detected significantly faster than control changes, t (20) = -2.50, p = .022. Eye changes were also detected significantly faster than control changes t (20) = -3.841, p = .001. In contrast, arrow changes did not differ significantly from control changes t (20) = -.263, p = .796. There was no evidence of arrow-cueing; arrow cued changes did not differ from control changes, t (20) = .539, p = .596. Finally, eye changes were detected significantly faster than gaze cued changes, t (20) = -4.06, p < .001. See Figure 3.6 for a graph of performance from the first five trials.

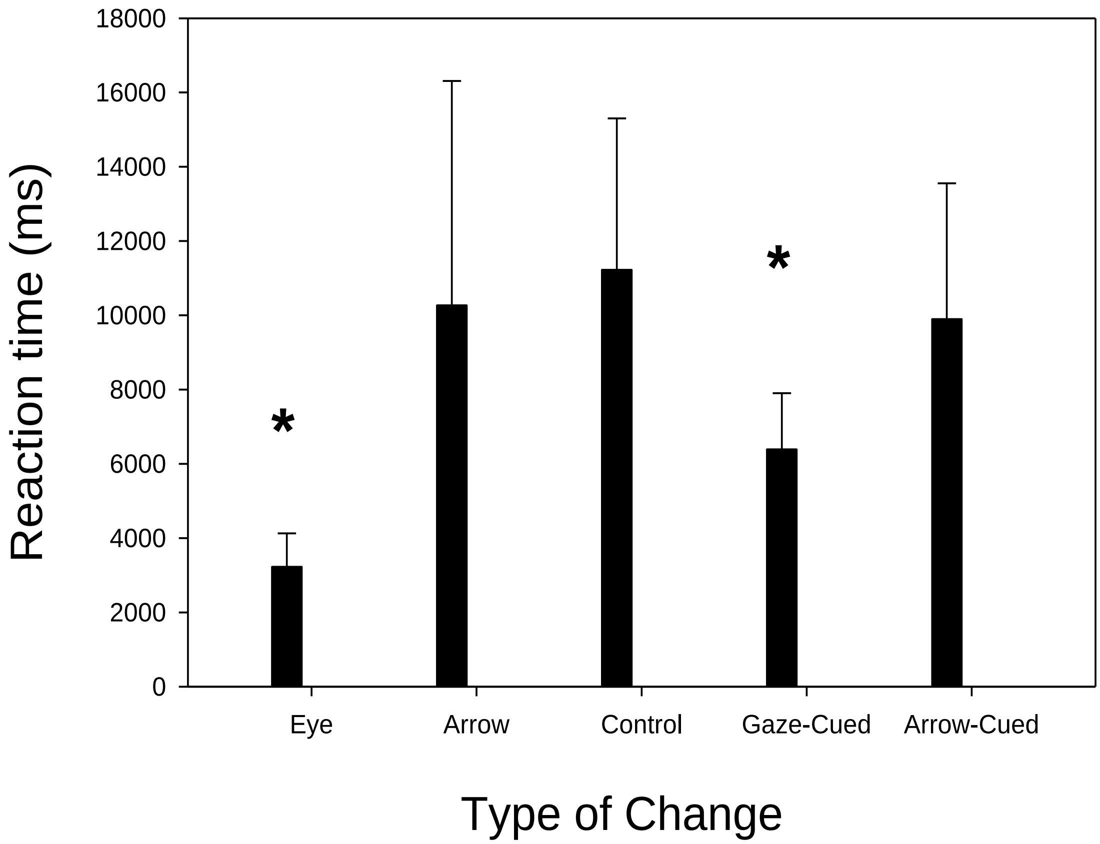


Figure 3.6. Data from first five trials: mean reaction time performance in milliseconds (ms) (+ 95% confidence intervals) for each experimental trial type in experiment 2. * indicates a statistically significant difference at $p < 0.05$.

Analyses were conducted to determine whether participants used a search strategy irrespective of cues to detect changes. Recall that a grid broke the screen up into 9 sections so that the accuracy data could be recorded. A repeated measures ANOVA on mean RT with screen section (1 through 9) as a within subject factor, revealed a significant main effect for screen section, $F\ (8, 160) = 6.52$, $p < .001$. Figure 3.7 shows that this effect was likely driven by faster mean RTs for screen sections 5, 6, and 8. This finding is in keeping with a central visual bias that is often observed when participants view a screen (Tatler, 2007).

12743.40 ms	13293.33 ms	11640.15 ms
14217.88 ms	7033.21 ms	6822.93 ms
13197.68 ms	8367.87 ms	12497.79 ms

Figure 3.7. Mean reaction time performance in milliseconds (ms) for all 9 sections of the screen display used to record location of change.

3.2.1. AQ results

Mean AQ scores were within the normal range. Only one participant scored in the clinically significant range therefore, it was not possible to examine trends for "high scorers". There were no significant correlations between AQ scores and task performance.

3.3. Discussion

When gaze and arrow cues were presented simultaneously and competed for attention, the results supported the prediction that eyes are prioritized and selected over arrow cues. For example, participants were significantly faster at detecting changes to the eye region as compared to changes to arrows or control changes. Gaze-selection appeared highly robust; participants quickly and accurately detected changes to the eye region, despite these changes occurring on very few trials (6%). Changes to the eye region were detected, on average, significantly faster than control changes, or any other type of change. This finding is consistent with previous research showing that faces and eyes tend to attract attention in a seemingly automatic fashion (Langton et al., 2008; Theeuwes & Van, 2006). In contrast, mean RTs for arrow changes were not significantly faster than control changes and do not attract attention anymore than other scene elements (Birmingham et al., 2009a).

Results did not support the prediction that participants would display spontaneous orienting to gaze and arrow cues with a greater cueing magnitude for gaze. Contrary to previous findings showing spontaneous orienting to gaze (Freeth, Chapman, et al., 2010; Freeth, Ropar, et al., 2010; Langton et al., 2006), participants in the current study did not locate gaze-cued changes faster than arrow or control changes, suggesting that they did not spontaneously follow gaze direction. However, analyses of the first five trials revealed that participants demonstrated preferential gaze cueing. Possibly, participants had an early bias to follow gaze but that this bias was attenuated over the course of the experiment as participants learned that gaze direction did not accurately predict the location of the change. Anecdotal comments from participants were consistent with this interpretation.

The pattern for attention for gaze was different for attention for arrows. Gaze selection and orienting to gaze were clearly different: selection of the eye region was fast and seemingly spontaneous and a significantly slower gaze following bias appeared initially but then faded. No similar pattern was found for arrow cues. Arrow-cueing did not facilitate change detection, neither initially nor for the remainder of the task. Lack of arrow-cueing and presence of early gaze-cueing suggests that gaze and arrows, when competing for attention in naturalistic scenes, may not trigger equal orienting responses.

It was not possible to test the prediction that higher AQ scores would positively correlate with less spontaneous gaze-cueing. Examination of the relationship may have been limited by the fact that only one participant fell in the “high scorer” range.

4. Experiment 3

In Experiment 2, selective attention for gaze occurred faster than orienting to gaze cues suggesting that these processes may be sequential. It is possible that gaze-selection allows for noticing of gaze-direction and therefore occurs prior to orienting to gaze (Birmingham & Kingstone, 2009). Alternatively, faces/eyes and their direction are computed pre-attentively and trigger shifting of attention towards the gazed-at object without the need to initially select the eyes (Langton et al., 2006).

In this experiment the temporal relations between gaze-selection and orienting to gaze were examined. In a novel manipulation, a series of time limits were set to explore temporal trends similar to those that would be seen in data from an eye-tracking task. Scenes with competing gaze and arrow cues were presented for short (2 scene cycles; 500 ms of viewing the changed scene), medium (4 scene cycles; 1000 ms of viewing changed scene), and long viewing times (8 scene cycles, 2000 ms of viewing the changed scene). TD adult participants then made a forced choice (i.e. yes/no) response indicating whether they saw a change. This forced choice paradigm was modeled upon Langton and colleagues' (2006) Experiment 2. The relationship between task performance and ASD-like traits was examined using the AQ.

It was anticipated that detection of eye-changes (gaze-selection) would be faster as compared to gaze cued changes (orienting to gaze or gaze-following). It was predicted that arrows would be largely ignored based upon findings from Experiment 2 and previous work showing that arrows are rarely focused on during scene viewing (Birmingham et al., 2009a). Different attentional patterns were predicted for eye-gaze vs. arrows (i.e. greater rates of gaze-selection and following at shorter time intervals) and the participants with higher ASD traits were expected to show reduced selection and following of gaze.

4.1. Methods

4.1.1. Participants

Thirty-one undergraduate students (90% female, mean age = 20.3 years) from Simon Fraser University (SFU) participated in the following experiment. Mean AQ scores fell within the average range for this group (overall mean = 18.03, males = 22.30, females = 17.56). All participants were naïve to the purpose of the experiment. They had normal or corrected-to-normal vision and did not self-identify as having ADHD. Pilot testing was run on 5 participants to ensure that timing intervals were feasible.

4.1.2. General procedure

The general procedure was the same as in Experiments 1 and 2.

4.1.3. Apparatus and Stimuli

Apparatus and stimuli were the same as in Experiment 2 with the exception of the addition of 6 new eye change scenes and 3 new arrow change scenes. One control change was removed and made into an arrow change. New, more subtle eye change scenes were added in order to attempt to address the concerns that eye changes may have been too obvious in Experiment 2. In particular, eye-changes in Experiment 2 had all consisted of a pair of sunglasses appearing or disappearing from the person within the photograph's face, with the dark sunglasses contrasting against paler faces. The new eye change scenes consisted of either wire-rim glasses or blue eye shadow appearing or disappearing on a person's eye region (please see Figure 4.1 for an example). New arrow change scenes were added so that the number of eye change and arrow change scenes would be equal. Participants viewed a total of 61 scenes/trials comprised of: 4 practice trials, 6 filler scenes, 9 eye changes, 9 arrow changes, 9 arrow-cued changes, 9 gaze-cued changes, and 15 control changes. Both gaze and arrow cues were non-predictive. All scenes contained a change but participants were not told that this was the case. As in previous experiments, trials were presented in random order (generated by E-prime).

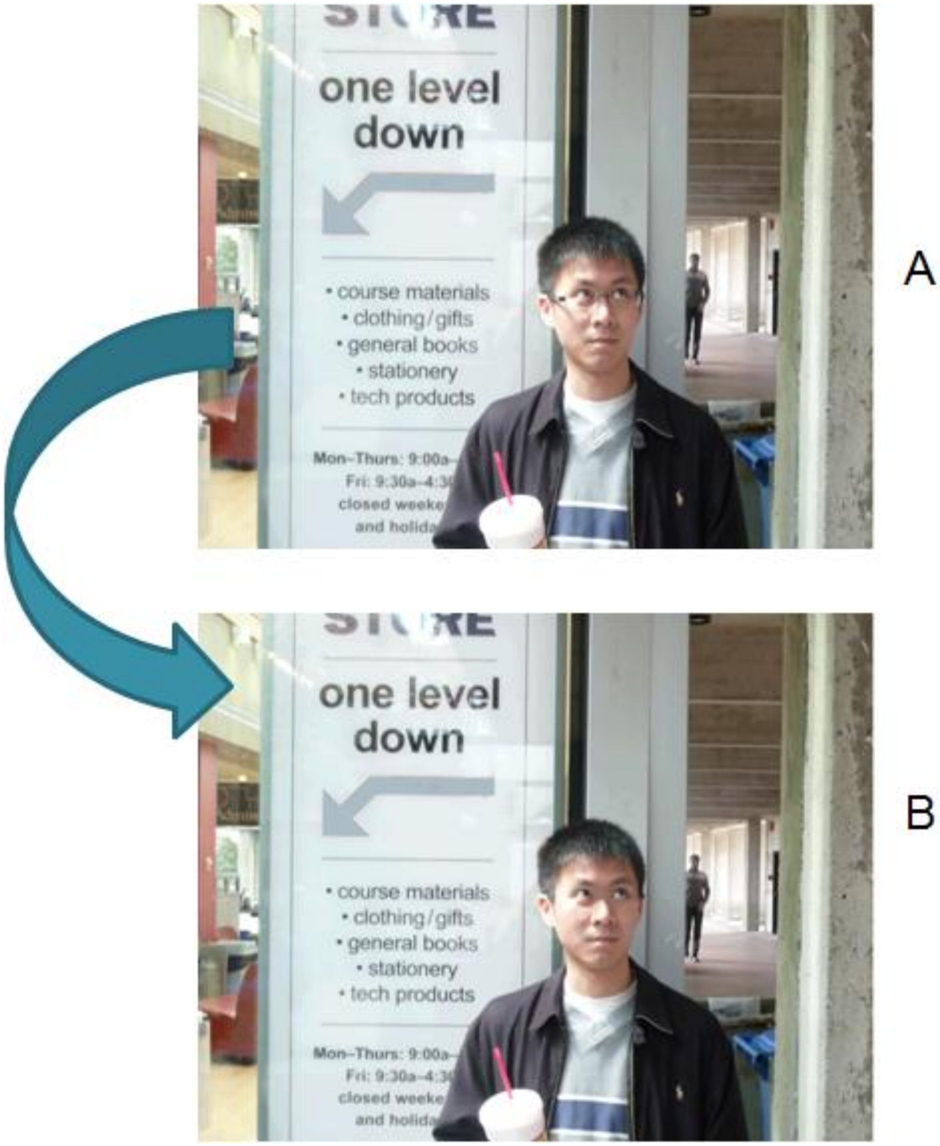


Figure 4.1. Example of one of six subtle eye change scenes added to experiment 3.

4.1.4. Design

Similar to Experiment 2, a within subjects repeated measures design was used. The five experimental changes (eye changes, arrow changes, gaze-cued, arrow-cued, and control) were distributed over 3 viewing time durations: short (2 cycles), medium (4 cycles), and long (8 cycles). In contrast with Experiment 2, the main dependent variable of interest was accuracy of change detection because presentation times were pre-set in the current forced choice design. Please refer to Table 4.1 for details of how trials were distributed.

Table 4.1. *Number of experimental trials of each type presented at each viewing time.*

	Short (2 cycles)	**Medium (4 cycles)**	**Long (8 cycles)**
Eye change	3	3	3
Arrow change	3	3	3
Gaze-cued change	3	3	3
Arrow-cued change	3	3	3
Control change	5	5	5

To ensure that systematic variability in change difficulty across experimental trial types would not confound results, it was ensured that norming means were equivalent across change type and time durations prior to running the experiment. A repeated measures ANOVA on norming means (see the norming of change difficulty description of Experiment 2 for more details) with trial type (gaze-cued change, arrow-cued change, and control change) and viewing time (short, medium, and long) as within subject factors revealed no significant interactions between trial type and viewing time, $F\ (68) = .21$, $p > .05$, reflecting equivalent norming means for gaze-cued, arrow-cued and control scenes. This type of norming was not possible for eye change trials and arrow change trials because covering over the directional cue also obscured the area of change. However, as in Experiment 2, eye-change and arrow-change trials were matched in terms of the centrality of the cue within the scene. Arrow trials were also made more salient because, as in Experiment 2, half of the arrows were highlighted.

4.1.5. Procedure

This experiment differed from previous ones in that participants viewed the flickering screen for a pre-determined duration (viewing time) and then made a forced choice as to whether they had spotted a change. Participants did not have control over how long they viewed each scene. Each trial began with a 250 ms presentation of the original version of a scene, followed by an 80 ms blank grey screen, presentation of the modified scene for 250 ms, and then the 80 ms blank. The sequence was repeated for one of 3 different durations or viewing times: short (2 cycles, or 500 ms), medium (4 cycles, or 1000 ms), or long (8 cycles, or 2000 ms). After the given duration, a screen appeared asking the participant if they had seen the change providing an accuracy measure. Participants used the mouse to click on either "yes" or "no". If the participant chose "yes", they then had to accurately indicate the location of change by clicking on the appropriate grid area as in Experiments 1 and 2. If the participant chose "no", they continue on to the next scene. Please see Figure 4.2 for an illustration of the sequence events during a trial in Experiment 3. All scenes contained changes. Accurate change detection was defined by selection of "yes" followed by clicking on the appropriate grid area. The likely-hood of accurate responding based on chance alone was very low (i.e. 6% for each trial).

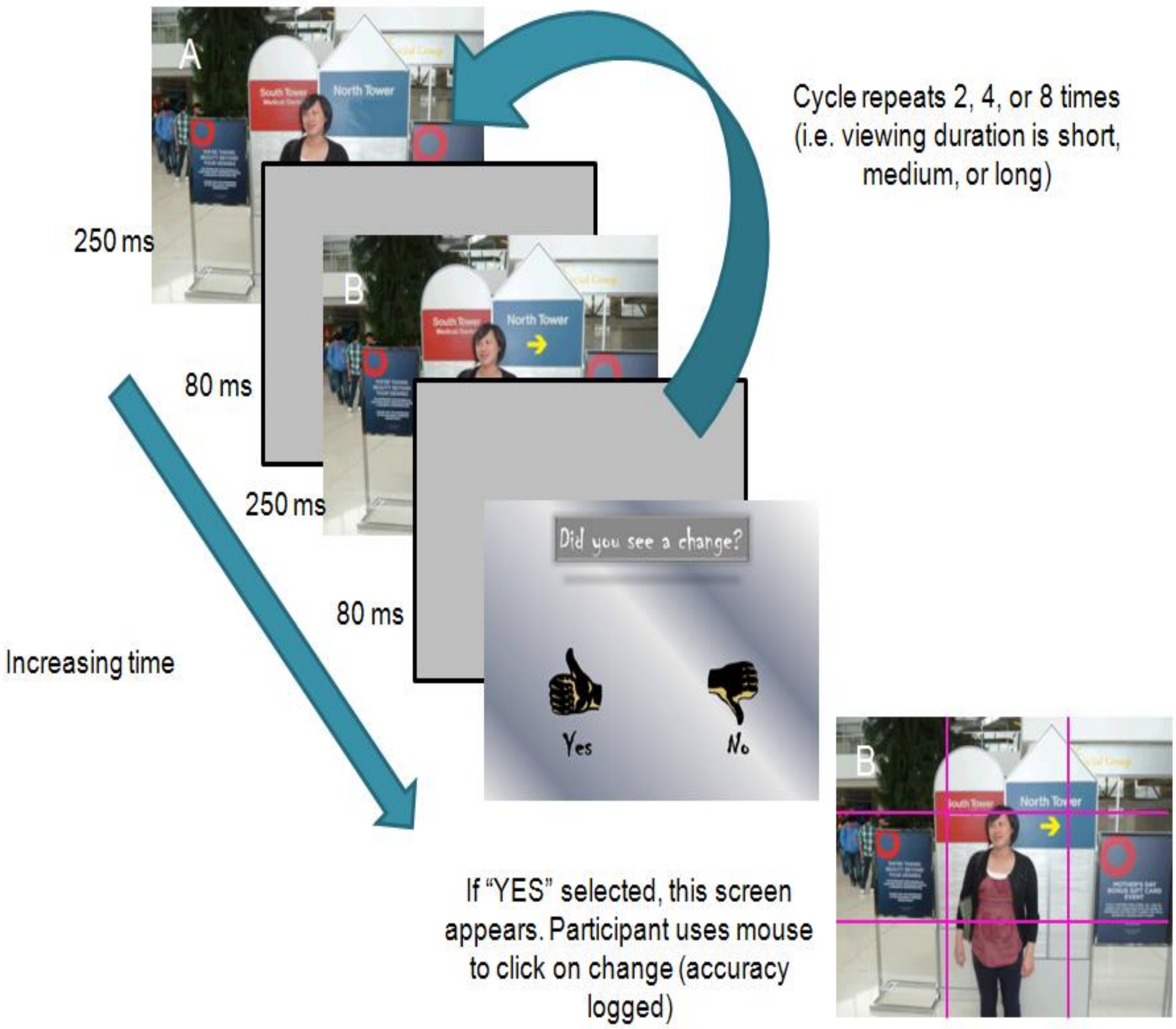


Figure 4.2. Example of the sequence of events during a trial in experiment 3.

4.2. Results

Mean percentage accuracy was calculated for each trial type and viewing time. Overall, participants found this task challenging and accurately located less than half of the changes (46%). Please see Figure 4.3 for a graphical representation of omnibus results for Experiment 3.

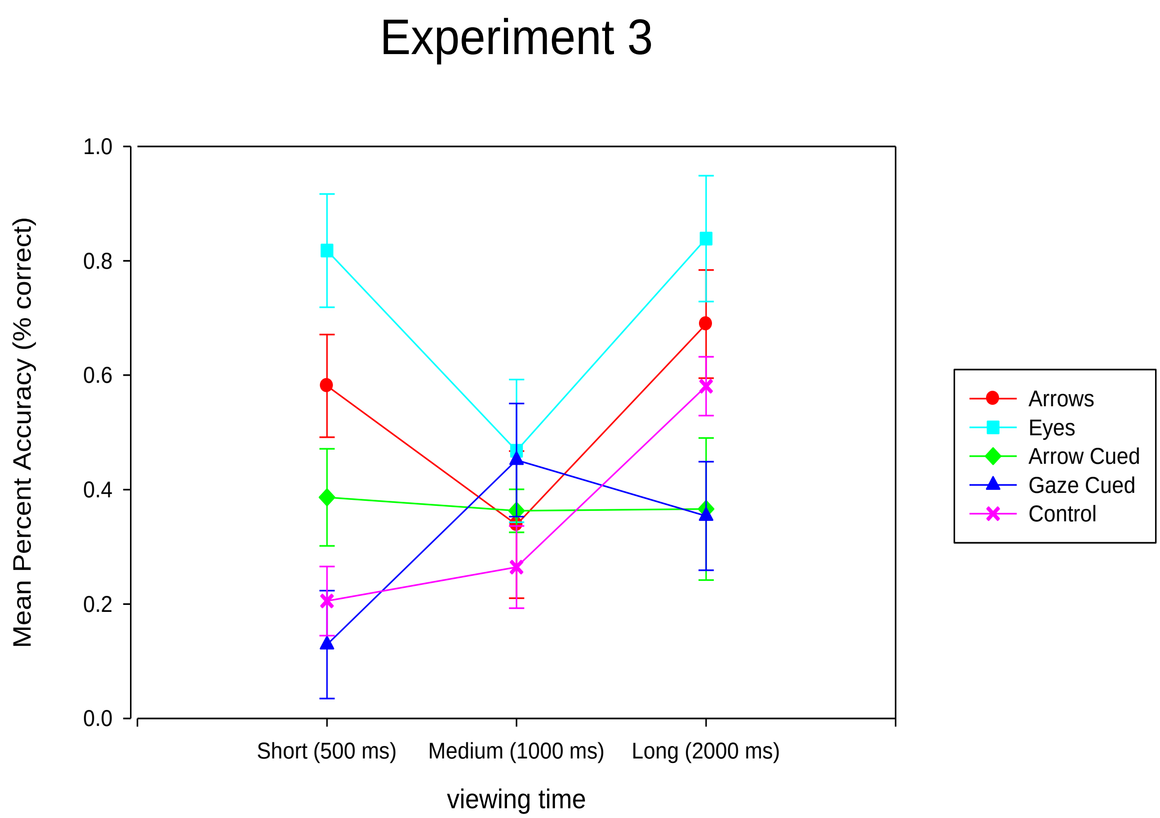


Figure 4.3. Overview of results from experiment 3. Mean percentage accuracy for each change type at the short, medium, and long viewing times with errors bars representing 95% confidence intervals.

For ease of interpretation, data was separated so that selective attention performance (i.e. accuracy on eye change vs. arrow change vs. control trials) was analyzed independently from following performance (i.e. accuracy on gaze-cued vs. arrow-cued vs. control trials).

4.2.1. Selective attention

A repeated-measures ANOVA (following confirmation of assumptions) was run on mean percent accuracy with selective attention trial type (eye change, arrow change, control change) and viewing time (short, medium, long) as within subjects factors. A significant main effect of cue type was found, $F\ (2, 60) = 29.18$, $p < .001$, reflecting significant differences in accuracy between the cue types (i.e. eye changes > arrow changes > control changes). A significant main effect of time was also found, $F\ (2, 60) = 55.91$, $p < .001$ which likely reflected differences in accuracy across viewing times (i.e. long > short > medium durations). There was also a significant interaction between trial type and viewing time, $F\ (4, 120) = 8.29$, $p < .001$. Paired samples t-tests were used to explore this interaction and Bonferonni corrections were performed to correct for multiple comparisons (i.e. the alpha value was adjusted to $\alpha = .008$). Pair-wise tests revealed that participants were more accurate at detecting eye changes than arrow changes at the short duration, $t\ (30) = -3.580$, $p = .001$, but not at the medium and long durations. They were more accurate at detecting eye changes than control changes at short, $t\ (30) = 11.178$ $p < .001$, medium, $t\ (30) = 2.862$, $p = .008$, and long durations, $t\ (30) = 4.221$, $p < .001$. Participants were more accurate at detecting arrow changes than control changes at the short duration, $t\ (30) = 7.583$, $p < .001$, but not at medium and long durations. See Figure 4.4 an illustration of mean percentage accuracy across viewing times for selective attention trial types.

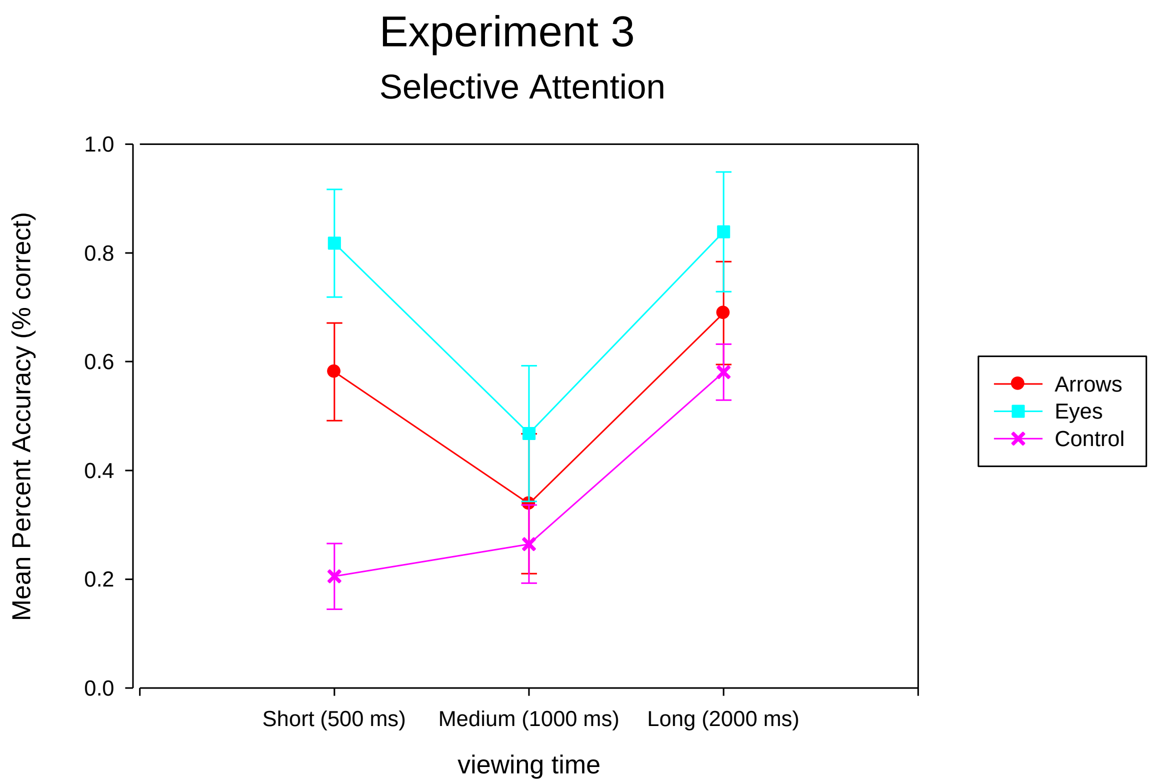


Figure 4.4. Mean percentage accuracy as a function of selective attention trial type for experiment 3. Error bars represent 95% confidence intervals.

4.2.2. Following of cues

A repeated-measures ANOVA (following confirmation of assumptions) was run on mean percent accuracy data with cue following trial type (gaze-cued change, arrow-cued change, control change) and viewing time (short, medium, long) as within subjects factors. There was no significant main effect of cue type. However, a significant main effect of timing was found, F (2, 60) = 19.23 $p < .001$, reflecting better accuracy at longer intervals than shorter ones. A significant interaction between timing and cue type, F (4, 120) = 11.36, $p < .001$ was found. Bonferonni corrected pair-wise comparisons (i.e. the alpha value was adjusted to $\alpha = .01$) were run. This indicated that participants were less accurate at detecting gaze cued than arrow cued changes at the short duration, t (30) = 4.534, $p < .001$, but not at the medium and long durations. They were more accurate at detecting gaze cued changes than control changes only at the medium duration, t (30) = 2.622, $p = .014$ and were less accurate at detecting gaze cued changes than control changes at the long duration, *t* (30) = -4.108, *p* < .001. Participants were more accurate at detecting arrow cued changes than control changes only at the short duration, *t* (30) = 7.583, *p* < .001, but participants were less accurate at detecting arrow cued changes than control changes at the long duration, *t* (30) = -3.123, *p* = .004. See Figure 4.5 for a graph of the mean accuracy for cue following cue following trial types across the three viewing times.

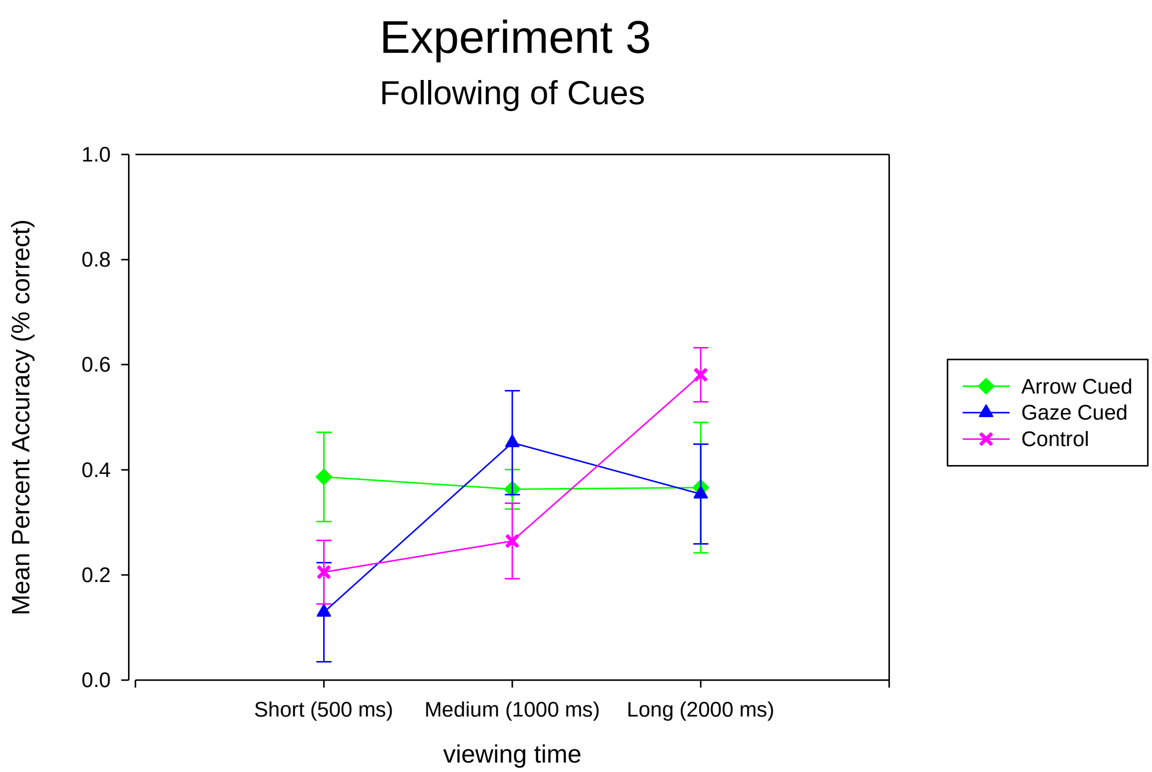


Figure 4.5. Mean percentage accuracy as a functioning of following trial types for Experiment 3. Error bars represent 95% confidence intervals.

4.2.3. Time course of processing

In order to explore whether selection of eyes occurred prior to gaze-following, a pair-wise t-test of performance at the short interval was conducted. It revealed higher accuracy for detection of eye changes as compared to gaze-cued changes, *t*(30) = 11.34, *p* < .001. At the medium interval, accuracy for detection of eye changes did not differ from detection of gaze-cued changes *t*(30) = .205, *p* = .839. At the long interval, accuracy for detection of eye changes was significantly more accuracte than gaze-cued changes, $t(3) = 6.99$, $p < .001$. In terms of trends in performance within trial type, there was a significant decrease in accuracy for detection of eye changes from short to medium intervals $t(30) = 6.52$, $p < .001$. Accuracy increased for detection of eye changes from the medium to the long intervals $t(30) = -5.67$, $p < .001$. For gaze-cued changes, there was a signficant increase in accuracy from the short to medium intervals $t(30) = -4.76$, $p < .001$ but no significant change from the medium to long intervals $t(30) = 1.32$, $p = .198$.

Bonferroni corrected pair-wise comparisons were also used to examine trends for arrow selection and following. At the short interval, change detection accuracy for arrow changes was higher than for arrow cued changes t (30) = 3.25, $p = .003$. There was no significant difference in terms of change detection for these two types of trials at the medium intervals t (30) = -.385, p = .703. At the long intervals, arrow changes were detected with more accuracy than arrow cued changes t (30) = 4.20, p < .001. Within trial type changes across timing intervals were also examined. Accuracy for arrow changes at the short interval was significantly higher than accuracy at the medium intervals t (30) = 3.42, $p = .002$ whereas accuracy increased signficantly between the medium and long intervals t (30) = -5.06, $p < .001$. Accuracy for detection of arrow cued changes remained stable across the three viewing time s with no significant changes from short to medium t (30) = .505, $p = .617$, or from medium to long intervals t (30) = -.052, $p = .959$.

4.2.4. AQ results

Mean AQ scores were within the normal range, with only two participants out of 31 scoring in the elevated range (greater than 26). There were no significant correlations between AQ scores and task performance.

4.3. Discussion

Experiment 3 examined the time course of selection and orienting to gaze cues. Scenes with competing gaze and arrow cues were presented for short, medium, and longer viewing times within a flicker task. Results from 31 undergraduate student participants suggest that gaze-selection occurred at short (500 ms) viewing times, gaze-following (i.e. orienting to gaze) at medium viewing times (1000 ms), and re-selection of the eyes at longer viewing times (2000 ms). At the shortest viewing time participants were most likely to attend to the eye region. Data suggest that selection of the eye region was highly robust and was significant across all viewing times. However, there was a coinciding decrease in selective attention for the eyes and a significant increase in orienting to gaze (over and above accuracy for control changes) at medium viewing times. Orienting to gaze did not continue at long viewing times. In contrast, participants appeared to switch back to selecting the eyes at the long viewing times. Thus, participants first selected the eye region, then many participants sometimes followed the eyes, then moved their attention back towards the eye region. The prediction that selection of eye-gaze is faster than orienting to gaze was supported.

The prediction that arrows would be largely ignored was not supported; selection and following occurred early and simultaneously for arrows. At the shortest viewing times, selection of arrows was significantly greater than attention for control changes. However, attention for arrows was less robust than eyes. Data indicated statistically significant arrow (but not gaze) following at the shortest viewing interval. Arrow-following remained at a moderate and consistent level across all viewing times but was only greater than control changes at the shortest interval. Further examination is required to understand why arrows were quickly selected and followed (as indicated by accuracy for change detection after viewing 2 scene cycles or 500 ms), despite indications from previous research that arrows are virtually ignored when viewed within real-world scenes (Birmingham et al., 2009a). Possibly, the artificial highlighting of the arrows increased visual saliency and drove greater attention for arrows.

Eyes and arrows were attended differently. There was evidence of a temporal serial pattern of attention for eyes: initially they were selected, then followed, then re-visited. However, the pattern for arrows was different as they were both significantly selected and followed at the shortest viewing time. One interpretation of this difference is that arrows (which serve the purpose of directing attention) are less visually interesting than eyes (which can convey a wealth of socially relevant information). Arrows may be simple to process and may not require much time before they are followed, whereas eyes may need to be processed more thoroughly in order to interpret the possible meanings and determine a strategy for gaze- following. This dovetails with evidence to suggest that arrows can be processed outside of the focus of attention, whereas this is not the case for eye-gaze (Burton, Bindemann, Langton, Schweinberger, & Jenkins, 2009).

Analyses of eye gaze selection and following and their associations with ASD traits was not possible due to only a few individuals with AQ scores in the elevated range.

5. Experiment 4

Visual attention can be drawn to an area of a scene based upon either: 1. behavioural relevance to the organism (e.g. eyes are highly relevant to social animals) or 2. low level properties of the scene such a luminance, colour, and location which is referred to as visual saliency (Itti & Koch, 2000). In this experiment visual saliency was manipulated and measured in order to explore its influence upon selection and following of gaze and arrow cue. In Experiment 3, arrow selection and following was more robust than anticipated (Birmingham et al., 2009a). Since arrows were artificially highlighted in previous experiments (in order to ensure that they would not be ignored and serve as a viable comparison cue to eyes), it is possible that attention for arrows was driven by their increased visual saliency.

In this experiment arrows first were de-emphasized and returned to their original appearance within photographs of scenes. Next, visual saliency analyses were run on original arrows, highlighted arrows, and eye regions in order to: 1. ensure that original arrows were indeed less salient than highlighted arrows, and 2. ensure that eyes were not salient as compared with arrows (i.e. gaze-selection was not due to low level scene properties). As in previous experiments, the AQ was administered to gauge level of ASD-like traits in TD adult participants.

Itti and Koch (2000) model was used to conceptualize and measure visual saliency. Within this model, visual saliency is thought to offer a good account of how viewers allocate attention to areas of a scene. Features are pre-attentively computed based on rapid and parallel processing of basic visual features including colour, intensity, and orientation. Input is then combined at each visual location which codes for location specific differences in features (e.g. how colours change across locations), resulting in separate topographic feature maps. Topographic maps then combine into three "conspicuity maps" which each account for intensity, colour, or orientation. Information from these conspicuity maps is summed into a final saliency map which locates the most salient scene areas. The “Winner-Takes-All” hypothesis predicts that the most salient location becomes the focus of visual attention. Attention is then moved to the next most salient location, and so on. Itti and Koch’s (2000) software and algorithm were used to calculate visual saliency.

It was predicted that when arrows were less salient, no significant arrow selection or following would occur at any of the viewing times. In contrast, it was expected that the pattern of gaze selection and following would be similar to the one found in Experiment 3. High levels of ASD-like traits as indexed by AQ scores were expected to be associated with less selection and following of gaze.

5.1. Methods

5.1.1. Participants

Thirty-five undergraduate students (90% female, mean age = 19.8 years) from Simon Fraser University (SFU) participated in Experiment 4. Data from two participants were excluded from the final analysis because of very low overall accuracy and associated behavioural observations indicating that these participants were not engaged in the task. Mean AQ scores for this group were as follows: overall mean = 17.60, males = 18.11, females = 17.12. All participants were naïve to the purpose of the experiment. They had normal or corrected-to-normal vision and did not self-identify as having untreated ADHD.

5.1.2. General procedure

The general procedure was the same as in Experiments 1 - 3.

5.1.3. Apparatus and Stimuli

The apparatus and stimuli were the same as in Experiment 3 but the arrows in the scenes were all un-highlighted and returned to their original appearance as photographed in the real world. Please see Figure 5.1 for an example of how arrows were un-highlighted. Also, three scenes were removed from the final analysis due to high error rates (i.e. two gaze-cued scenes where the change was not “foveated” or within the model's line of sight and one arrow-change scene where the change occurred on a grid-line).

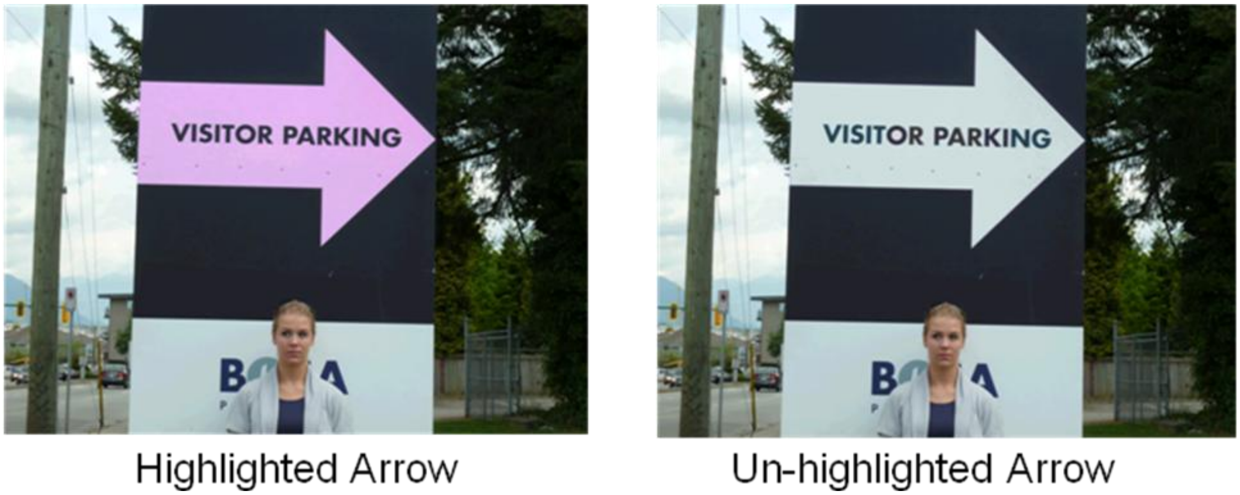


Figure 5.1. An example of a highlighted arrow used in experiment 3 on the left and the un-highlighted arrow used in experiment 4 on the right.

5.1.4. Design & Procedure

The experimental design and trial procedure were identical to those used in Experiment 3.

5.1.5. Saliency computation

Itti and Koch's (Itti & Koch, 2000) saliency model has been coded into software available at: [http://ilab.usc.edu/toolkit/downloads.shtml]. The program's default weightings were used. Saliency was coded in arrow regions (for both highlighted and non-highlighted arrows) and eye regions.

5.2. Results

5.2.1. Saliency analysis

Using visual saliency maps derived from software based upon Itti and Koch's (2000) model, the saliency of eyes and arrows in the original vs. highlighted arrow scenes were compared. The saliency maps confirmed that the arrows were less salient once they were returned to their original state and no longer highlighted and that the eyes were less visually salient than the arrows. Please see Figure 5.2 for an example of a saliency map.

Figure 5.2. An example of a saliency map (left) for a scene with a highlighted arrow (right).

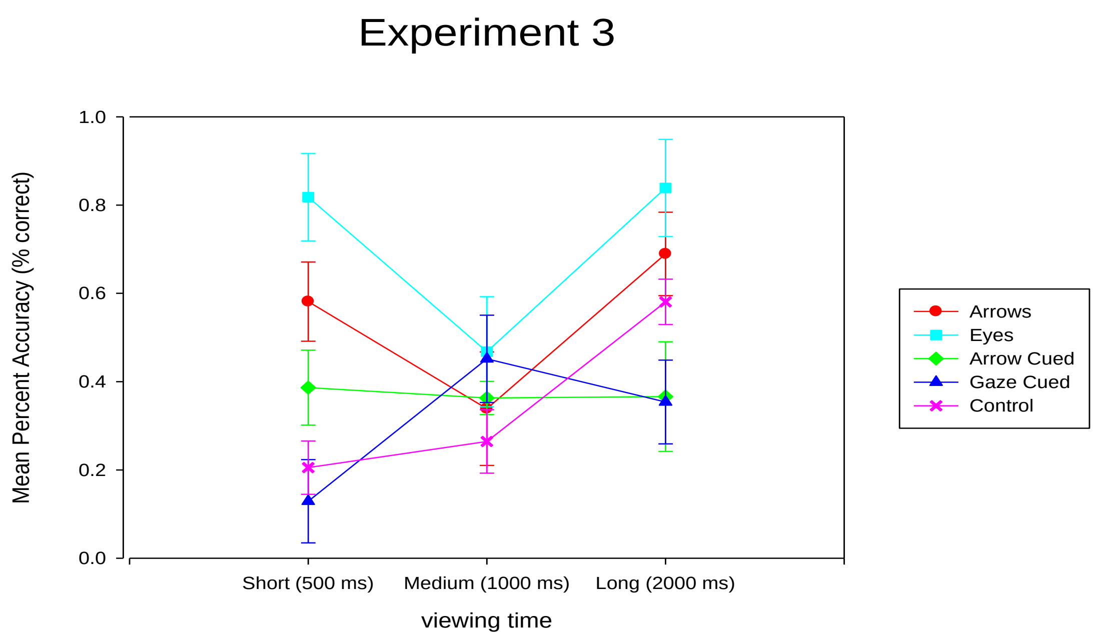
Wilcoxon signed rank tests showed that the original arrows were less visually salient than the artificially enhanced (i.e. highlighted) arrows (Z = -4.045, p < .000). Removal of the highlighting made the arrows significantly less salient. Another Wilcoxon signed rank test revealed that even when the arrows were presented in their original form, they were, on average more visually salient than eyes within the scenes (Z = -3.782, p < .000). On average, eyes were not salient and had a saliency value of 0 in most scenes.

5.2.2. Change detection analysis

Participants found Experiment 4 challenging and accurately located less than half of the changes (47%). Please see Figure 5.7 for a graphical representation of results from Experiment 4. As before, data was separated so that selective attention performance (i.e. accuracy on eye change, arrow change, and control trials) was analyzed independently from orienting performance (i.e. accuracy on gaze-cued, arrow-cued, and control trials).

5.2.3. Influence of visual saliency on attention for gaze and arrows.

There were some relatively minor yet noteworthy differences in the pattern of results between Experiments 3 and 4. Foremost, when arrows were not highlighted in Experiment 4, there was no significant arrow following at any viewing time (beyond accuracy for detecting control changes). Early selection of arrows still occurred at the short viewing times, but as in Experiment 3, it was less significant than eye selection. There were some differences in terms of following eye gaze cues between experiments. In Experiment 4, there was significantly less gaze-cueing at the short viewing times (almost at chance or 6%) and at the long viewing times. Although gaze cueing at the medium viewing times appears decreased in Experiment 4 as compared with Experiment 3, this visual difference was not statistically significant (gaze-cueing still occurred more than detection of control changes). Please see Figure 5.3 for a graphical comparison of findings from both experiments.



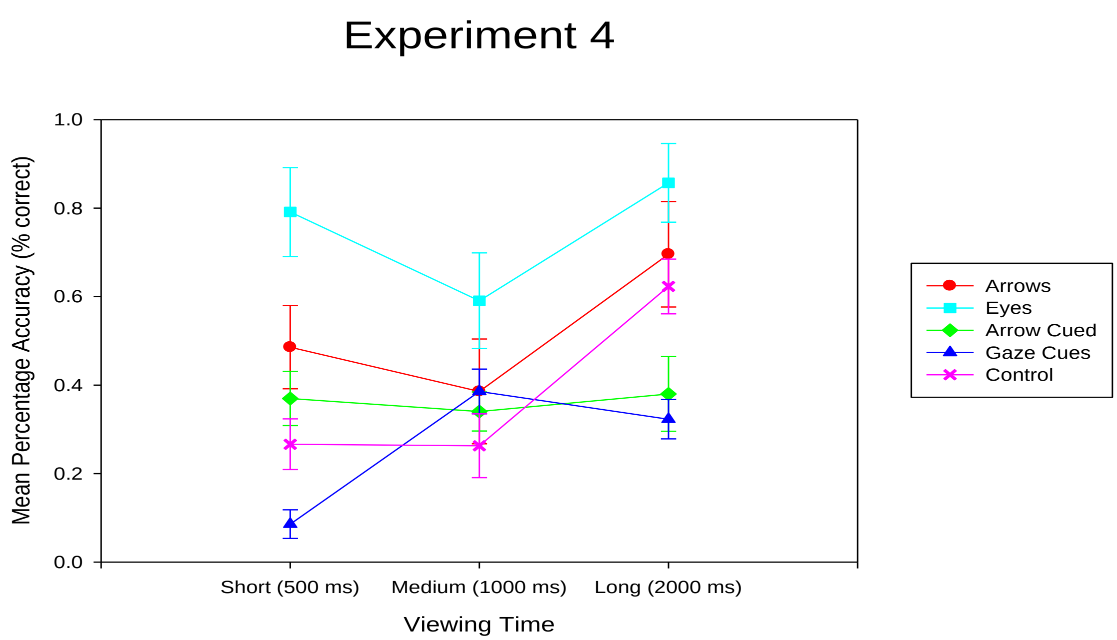


Figure 5.3. Results for experiments 3 (highlighted arrows) & 4 (original arrows). Error bars represent 95% confidence intervals.

5.2.4. Analysis of Experiment 4 data

5.2.4.1. Selective attention.

For Experiment 4 data, a repeated-measures ANOVA was run on mean percent accuracy with selective attention trial type (eye change, arrow change, control change) and time interval (short, medium, long) as a within subjects factors. A significant main effect of cue type was found, F (2, 68) = 8.98, p < .001, reflecting differences in accuracy across cue types (i.e. eye changes > arrow changes > control changes). A significant main effect of timing was found, F (2, 68) = 12.31, p < .001, indicating that participants were more accurate at detecting changes at long > short > medium viewing times. There was also a significant interaction between trial type and time interval, F (4,136) = 16.83, p < .001, which was explored with pair-wise comparisons. Bonferonni corrected pair-wise comparisons revealed higher accurate change detection for eye changes over arrow changes at the short duration, t (34) = -4.339, p < .001, but not at medium or long viewing times. Accuracy was higher for eye changes over control changes at the short, t (34) = 8.755, p < .001, medium, t (34) = 4.715, p < .001, and long viewing times, t (34) = 4.284, p < .001. Accuracy for arrow changes over control changes was significant at the short viewing times only, t (34) = 4.141, p < .001. No other pair-wise comparisons were significant. The pattern of selective attention results was identical to the findings from Experiment 3. See Figure 5.4 an illustration of mean percentage accuracy across viewing times for selective attention trial types.

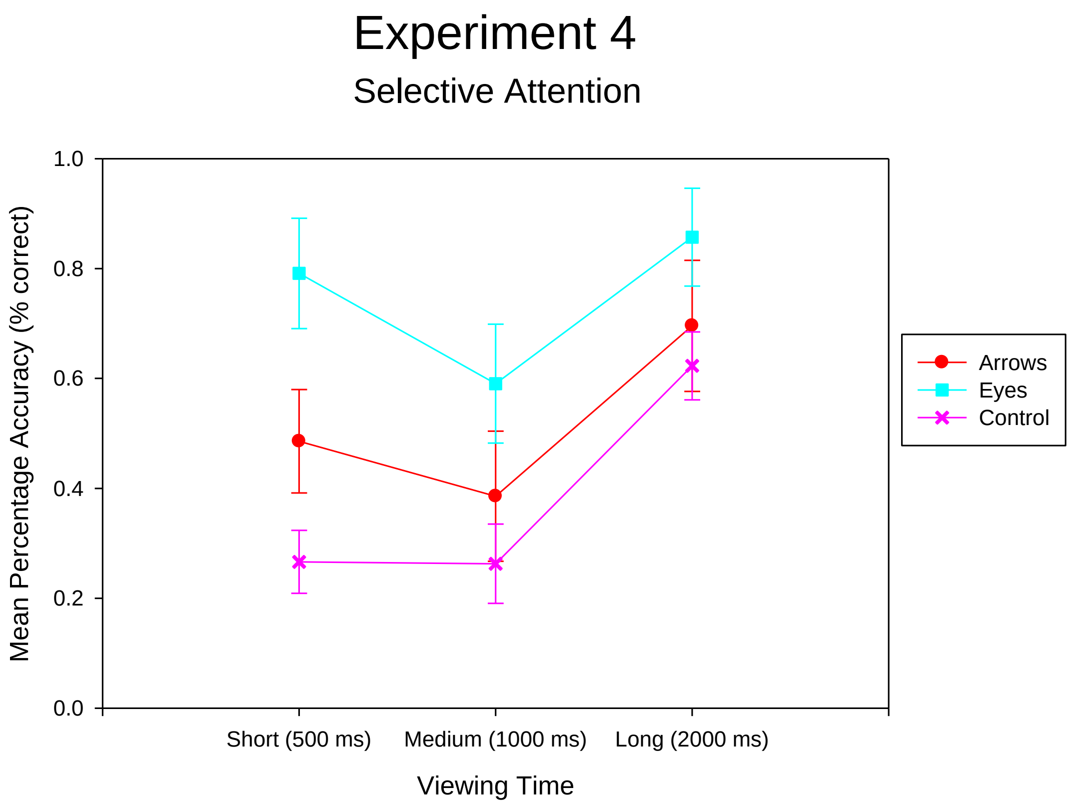


Figure 5.4. Mean percentage accuracy as a function of selective attention trial type for experiment 4. Error bars represent 95% confidence intervals.

5.2.4.2. Following of cues.

A repeated-measures ANOVA was conducted on mean percent accuracy data with orienting trial type (gaze-cued change, arrow-cued change, control change) and viewing times (short, medium, long) as within subjects factors. There was a significant main effect for trial type, F (2, 68) = 25.92, p < .001, reflecting differences in accuracy as a function of trial type (i.e. control > arrow > gaze). There was also a significant main effect of viewing times, F (2, 68) = 64.23, p < .001, reflecting that accuracy increased as viewing time increased (i.e. long > medium > short viewing times). There was a significant interaction between trial type and viewing times, F (4, 136) = 3.39, p = .011, which was explored with pair-wise comparisons. Bonferonni corrected paired samples t-tests revealed that participants were less accurate at detecting gaze cued changes compared to control changes at the short viewing times (performance was just above chance), t (34) = -4.887, p < .001 and long viewing times, t (34) = 6.078, p < .001. The only time when participants were more accurate at detecting gaze cued changes over control changes was at the medium viewing times, t (34) = -1.967, p = .05. This comparison was considered a-priori given that it was predicted based upon findings from the previous experiment. As such, Bonferonni corrections were not applied. Although arrow-cueing occurred to a greater extent than gaze-cueing at the short viewing times, t (34) = 6.587, $p < .001$, accuracy for arrow-cued changes was not significantly different from accuracy on control trials at the short, medium, or long viewing time. Please refer to Figure 5.5 for an illustration of mean percentage accuracy across viewing times and following trial types.

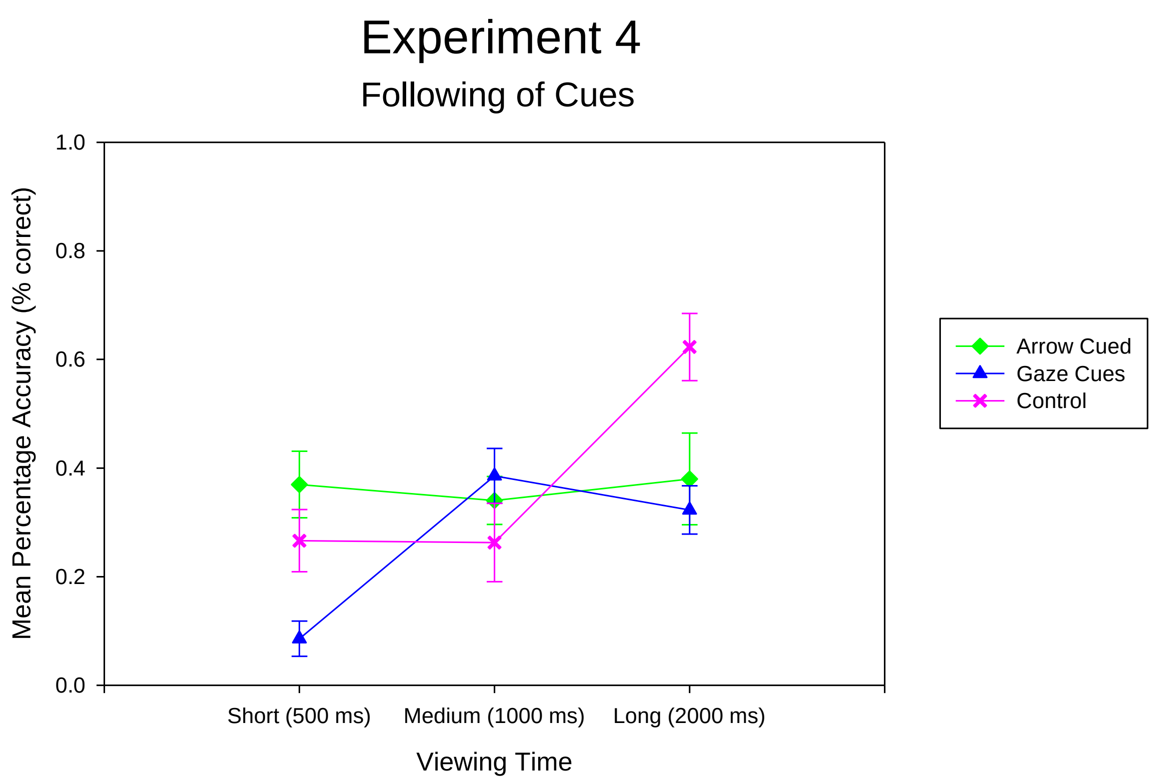


Figure 5.5. Mean percent accuracy as a function of orienting trial type for experiment 4. * indicates $p < 0.05$. Error bars represent 95% confidence intervals.

5.2.4.3. Time course of processing.

Trends were examined for selection of eyes as compared to gaze-following. A pair-wise t-test of performance at the short viewing times revealed higher accuracy for detection of eye changes as compared to gaze-cued changes, t (34) = 12.40, $p < .001$. At the medium viewing times, accuracy for detection of eye changes did not differ from detection of gaze-cued changes once alpha was adjusted to $\alpha = .008$ to account for multiple comparisons, t (34) = 2.49, $p = .018$. At the long viewing times, accuracy for detection of eye changes was significantly better than for gaze-cued changes, t (34) = 8.80, $p < .001$. In terms of trends in performance within trial type, there was a significant decrease in accuracy for detection of eye changes from the short to the medium viewing times t (34) = 3.64, $p = .001$. Accuracy increased for detection of eye changes from the medium to the long viewing times t (34) = -4.75, $p < .001$. For gaze-cued changes, there was a signficant increase in accuracy from the short to medium viewing times t (34) = -4.19, $p = .001$ but no significant change from the medium to long viewing times t (34) = -.958, $p = .345$. In sum, the pattern of results was identical to that of Experiment 3.

Bonferroni corrected pair-wise comparisons were also used to examine trends for arrow selection and following. At the short viewing times, change detection accuracy for arrow changes was no higher than for arrow cued changes, t (34) = 1.89, $p = .067$. There was no significant difference in terms of change detection for these two types of trials at the medium viewing times, t (34) = .74, $p = .466$. At the long viewing times, arrow changes were detected with more accuracy than arrow cued changes, t (34) = 4.36, $p < .001$. Within trial type changes across viewing times were also examined. Accuracy for arrow changes at the short viewing times was not significantly higher than accuracy at the medium viewing times, t (34) = 1.65, $p = .108$. There was a significant increase in accuracy between the medium and long viewing times for arrow changes, t (34) = 4.67, $p = .001$. Accuracy for detection of arrow cued changes remained stable across the three viewing times with no significant changes from short to medium, t (34) = 1.01, $p = .318$, or from medium to long viewing times, t (34) = -.340, $p = .736$.

5.2.4.4. AQ findings.

A significant correlation was found between eye-change detection accuracy at the short duration and AQ scores, r (31) = - 0.388, $p = .021$. As the participants' AQ scores increased, they were less accurate at detecting eye-changes at the short duration. There was also a significant correlation between control change detection accuracy at the long viewing time and AQ scores, *r* (31) = - 0.382, *p* = .024. This correlation appeared to be driven by scores on the switching attention factor of the AQ which reflect poorer self-reported ability to shift attention, *r* (31) = -.403, *p* = .017.

Out of the 35 participants, 3 were deemed "high-scorers" by virtue of having scores above 26 on the AQ (Baron-Cohen et al., 2001). High-scorers demonstrated significantly lower accuracy for detection of gaze cued changes at the medium viewing time as compared with participants with AQ scores in the normal range, *t* (33) = -8.31, *p* < .001. In particular, high scorers detecting significantly fewer gaze cued changes (M = 0 %, SD = 0%) as compared with average scorers (M = 42%, SD = 28%). When gaze-cueing accuracy was collapsed across the three viewing times, the same pattern emerged with high scorers detection significantly fewer gaze cued changes (M = 13%, SD = 3%) as compared with participants who scored within the average range on the AQ (M = 27%, SD = 13%), *t* (33) = -4.83, *p* < .001. See Figure 5.8 for a graph that depicts the performance of the 3 high scorers.

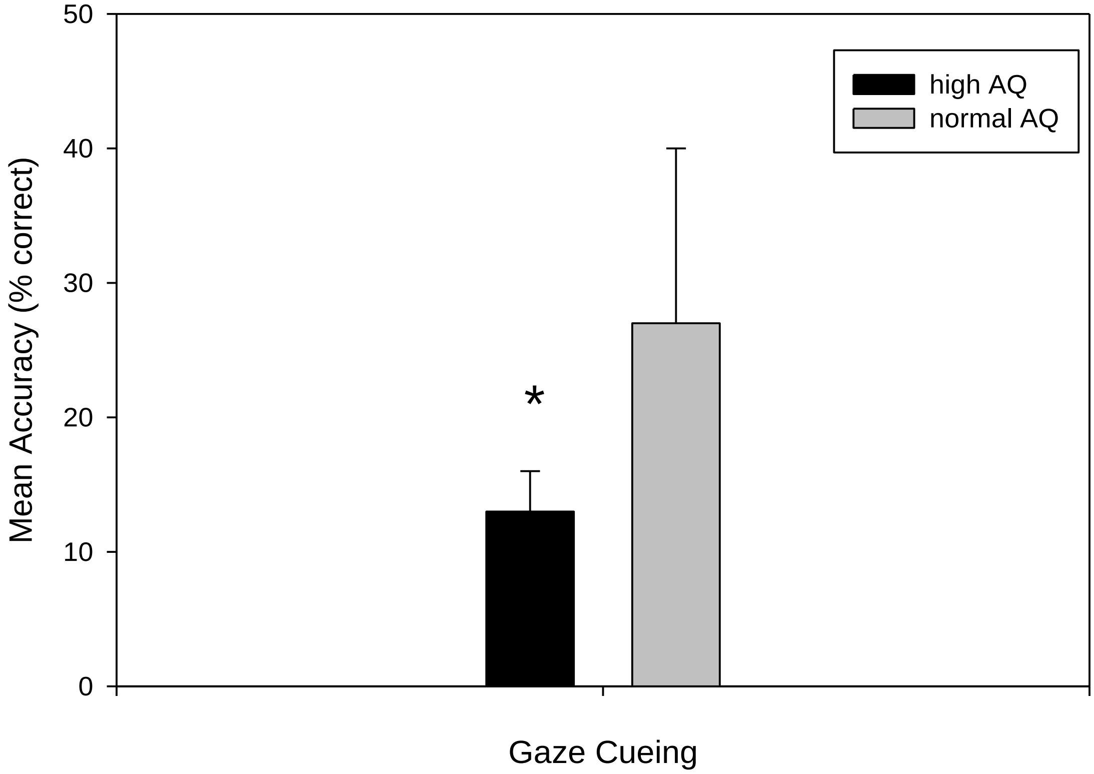


Figure 5.6. Mean percent accuracy for detection of gaze-cued changes (+ standard deviations) for participants with high (3) and average (32) AQ scores in experiment 4.* indicates significantly faster response time for valid cues, $p < .001$.

5.3. Discussion

This experiment explored the extent to which visual salience influenced the accuracy with which participants selected and followed arrows. When 35 undergraduate participants were shown the scenes with non-highlighted arrows, the pattern of results was essentially the same as in Experiment 3 with two notable exceptions. First, arrow-following was no longer significant (as compare with control changes). Second, there was a slight decrease in gaze-following at the short and long viewing times. Data partially support the prediction that when arrows are less salient, no significant arrow selection or following occurs. Arrow-following was no longer significant; however, participants continued to demonstrate significant arrow selection (but less pronounced than eye selection) at the short viewing time. When arrows were not highlighted, they were still selected but not followed.

It is unclear why significant early selection of arrows was found in contrast with previous studies showing that arrows are virtually ignored during scene viewing (Birmingham, Bischof, & Kingstone, 2009). There are a few possible explanation for early selection of arrows: 1. arrows were large and central in scenes, 2. arrows were repeated throughout scenes (so participants may have surmised that they were important) and/or 3. the arrows were often close to text (which has been shown to draw attention). A closer examination of stimuli for Experiment 4 reveals that 6 out of 51 arrows had text in them (12%) and 38 out of 51 were located on signs with text in close proximity (75%). Text has been shown to draw viewer's visual attention to the same extent as heads & faces (Birmingham, Bischof, & Kingston, 2009). Thus, the proximity of text and arrows in the current stimuli may explain the findings of significant selection of arrows. Although the presence of text and arrows can be a construed as a limitation of the present stimuli, arguably in the real-world, most arrows are associated with text. Thus, the current stimuli are likely ecologically valid although it may be interesting in future experiments to separate text and arrows in order to discern their unique attentional properties.

Data supported the prediction that the pattern of gaze selection and orienting to gaze would be similar to the one found in Experiment 3. Although there was a slight decrease in orienting to gaze orienting to gaze at the short and long viewing times in Experiment 4, the pattern of gaze selection and following was the same as in Experiment 3. The same serial pattern of early selection, moderate orienting to gaze and re-visiting eyes emerged. There was significantly less orienting to gaze at the short and long viewing times. In particular, orienting to gaze was almost at chance at the shortest viewing time. Overall, current findings indicate that orienting to gaze is less robust than previous reports indicate (Freeth, Chapman, et al., 2010; Freeth, Ropar, et al., 2010; Langton et al., 2006) and seems to occur only after gaze-selection.

The hypothesis was supported that high levels of ASD-like traits as indexed by AQ scores were associated with less selection and following of eye-gaze. A significant correlation was found between eye-change detection accuracy at the short duration and

AQ scores. Participants with higher AQ scores were less accurate at detecting eye-changes at the short viewing time, suggesting that individuals with higher self-reported ASD – like traits demonstrated less early gaze selection. There was another significant positive correlation between detection of control changes at the long viewing time and higher AQ scores. This correlation appeared to be driven by correlations with subscale scores on the switching attention factor of the AQ which reflect poorer self-reported ability to shift attention. Three participants with high levels of AQ-like traits ("high-scorers") demonstrated significantly less orienting to gaze at the medium viewing time and overall. However, given the small number of high-scoring participants, it's not possible to draw conclusions based upon the current data and further replication of findings is required.

6. Experiment 5

This experiment explored whether adults with and without ASD select and orient attention to gaze and arrow cues differently. The performance of adolescents and young adults with ASD was compared with that of TD comparisons using the flicker task from Experiment 4. This task measured attention for and use of eye-gaze and arrow cues across three different time durations [i.e. short (500 ms), medium (1000 ms), and long 2000 ms]. It was anticipated that participants with ASD would demonstrate reduced early selection of gaze and reduced orienting to gaze cues as compared to their matched TD peers.

6.1. Methods

6.1.1. Participants

Ten individuals with ASD participated in Experiment 5. One person's data was excluded from the final analysis because this participant did not understand the task and their change detection accuracy was at chance level. Another participant's data was excluded because their Abbreviated IQ (ABIQ) fell within the Intellectual Disability range. Data from the remaining 8 participants with ASD (7males, mean age = 19.19 years, ranging from 14 to 25 years) was matched with data from 8 SFU TD students (7 males, mean age = 18.25 years, ranging from 15 to 21 years) on the basis of age and sex. Age was not correlated with task performance.

Comparison data was from 9 new undergraduate students and one 15 year old SFU student who had been excluded from a previous experiment due to her young age. They were group matched with ASD participants on the basis of age and individually matched based on sex. Participants with ASD were excluded if they had an IQ below 75. The data for two undergraduate students was excluded when 2 ASD participants were excluded from the study.

ASD diagnostic status was confirmed via one or several of the following methods: an ADI-R interview was located on file in our laboratory (3 participants), a copy of a diagnostic report from a Qualified Specialist in BC was received (2 participants), or for participants who were unable to provide a report (3 participants), their parents were contacted to confirm that they had received a diagnosis of ASD from the Provincial Autism Resource Center or another Qualified Specialist in BC, which is a clinically rigorous and provincially standardized method.

6.1.2. Measures

The *Abbreviated Standford-Binet (Fifth Edition)* was administered to all ASD participants in order to assess their cognitive functioning. Two participants with ASD were excluded because their IQs were lower than 75. Remaining abbreviated IQ's [ABIQ (Mean = 113.13, ranging from 100 to 133)] were deemed comparable with the TD sample (although no IQ data was available from this group). Of note, IQ was not correlated with task performance. The overall performance accuracy of the ASD sample on the flicker task did not differ significantly from the TD sample, t (14) = .472, p = .644. Participants with ASD were 44% (SD = 6%) accurate on average whereas comparisons were 42% (SD = 5%) accurate on average.

All participants or their parents completed the *Autism Spectrum Questionnaire* (AQ: Baron-Cohen et al., 2001), either the adult or adolescent version depending upon age. Mean for AQ scores for ASD participants fell in the normal range at 24.81, but scores ranged into the clinical range (12 - 37, SD = 8.99). This was lower than the mean AQ scores in a large sample of adults with high functioning ASD who scored 35.62 on average (Woodbury-Smith, Robinson, Wheelwright, & Baron-Cohen, 2005). This may have been driven by problems with insight on the part of the ASD participants (e.g. overestimating their social skills) as several participants rated themselves as low on the AQ but exhibited social deficits during interactions with the examiner. ASD scores were significantly higher than AQ scores from the TD sample (mean AQ = 16.75, range = 11 – 27, SD = 4.89), t (16) = 2.12, p = .044.

For those ASD participants who were 18-years-old and younger (4 participants), I asked their parents to complete the *Social Responsiveness Scale* (SRS), which measures: "the severity and type of social impairments that are characteristic of autistic spectrum conditions in children and adolescents" (Constantino & Gruber, 2005). The mean SRS score for ASD participants was 77 (ranging from 72 to > 90) which fell within the clinical range and indicated that, according to parental report, our participants exhibited mild to moderate social impairment characteristic of high functioning ASD.

All participants with ASD (with the exception of one person) had either a clinically elevated AQ or SRS score. The one participant who rated themselves as scoring 12 on the AQ had a confirmed diagnosis of ASD from a Qualified Specialist. Their parent was contacted to confirm that they still were experiencing social difficulties in everyday settings.

6.1.3. General procedure

Details of the study were described to participants and written informed consent was obtained from the participant, their parent/guardian, or both (in keeping with guidelines outlined by SFU's department of research ethics who granted approval for this project). Participants then filled out a brief demographics survey form (e.g. age, sex, vision) and the AQ questionnaire. The parents of participants who were 18 years old or younger filled out the SRS. Participants then completed the computer flicker task followed by completion of the Stanford-Binet. Participants were given a movie pass or book-store gift card worth $10 for their time.

6.1.4. Apparatus and Stimuli

The apparatus and stimuli were the same as in experiment 4.

6.1.5. Design & Procedure

The experimental design and trial procedure were identical to those used in Experiment 4.

6.2. Results

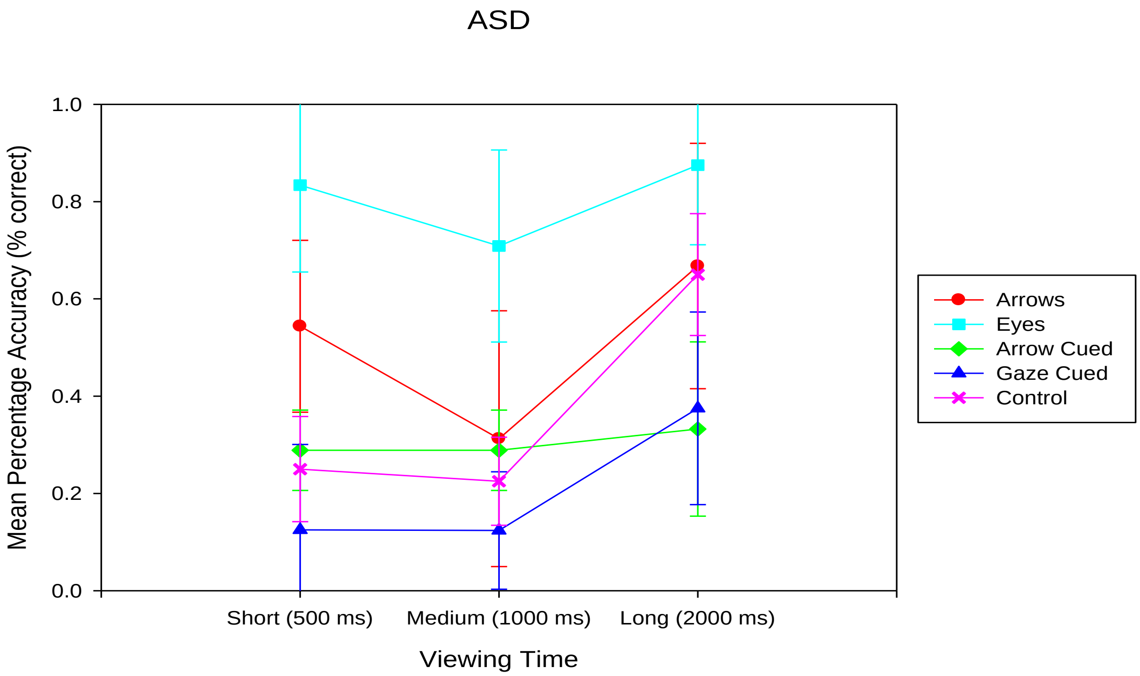
Prior to analysis, assumption tests confirmed normality of the data (Shapiro-Wilk tests on DVs were significant). Please see Figure 6.1 for a graphical depiction of results from Experiment 5. A repeated measures ANOVA was conducted on mean percent accuracy scores with group (ASD, TD) as a between subjects factor and change type (arrow, eye, control, gaze-cued, arrow-cued) and viewing time (short, medium, long) as within subject factors. There was no significant main effect of diagnosis, F (1, 14) = .024, p = .643, indicating that mean overall accuracy levels did not differ between groups. There was a significant main effect of cue type, F (4, 56) = 28.18, p < .001, reflecting a higher mean accuracy for detecting eye changes in all participants. A significant main effect was also found for timing, F (2, 28) = 35.23, p < .001. This reflects that mean accuracy improved at longer viewing times for all participants. There was a significant interaction between cue type and viewing times, F (8, 112) = 5.63, p < .001, indicating that accuracy fluctuated across cue types at different viewing times. There was also a significant interaction between cue type, viewing times, and diagnosis, F (8, 112) = 2.43, p = .019. This interaction was explored further with a post-hoc independent samples t-tests (Bonferonni corrected) which indicated that the only significant difference between groups was for gaze-cueing accuracy at the medium viewing times, t (14) = -3.61, p = .003. TD participants demonstrated significantly higher levels of gaze following at the medium viewing time (M = 50% accuracy) as compared to their ASD comparisons (M = 12% accuracy). Since the chance of randomly selecting the correct response was approximately 6% for each trial, this indicates that participants with ASD followed eye-gaze just above chance.

Planned paired-samples t-tests were conducted to explore the time course of social attention. TD participants demonstrated significant selection of eye changes relative to control changes at the short viewing time, t (7) = -7.80, p < .001, but not at the medium viewing time. They also demonstrated a significant decrease in accuracy for detection of eye changes from the short viewing time to the medium viewing time, t (7) = 3.74, p = .007, and an increase in detection of gaze-cued changes at the medium viewing time, t (7), = -7.00, p < .001. Further, detection of gaze-cued changes was significantly more accurate than detection of control changes at the medium viewing time, t (7) =

3.96, p = .005, for TD participants. Thus, eye-gaze trends were virtually identical to Experiments 3 and 4 except that there was no re-visiting of the eyes at the long viewing time in the current experiment.

In contrast, participants with ASD appeared to maintain their attention upon the eye-region across all viewing times. Selection of eyes was significant relative to control changes at the short viewing time, t (7) = 5.16, p =.001, the medium viewing time, t (7) = 4.40, p = .003. Participants with ASD did not have significantly higher accuracy rates for detecting gaze-cued changes over control changes at any of the three viewing times.

TD participants did not demonstrate significant early selection of arrows relative to control changes. At the short viewing time, their accuracy for detection of eye-changes was significantly higher than detection of arrow changes, t (8) = -4.79, p < .05. In contrast, participants with ASD demonstrated significant early selection of arrows over accuracy for detection of control changes, t (7) = 3.31, p < .05. Early selection of arrows did not differ significantly from early selection of eyes for participants with ASD. Neither group demonstrated any arrow-following.


ASD
Mean Percentage Accuracy (% correct)
1.0
0.8
0.6
0.4
0.2
0.0
Short (500 ms)
Medium (1000 ms)
Long (2000 ms)
Viewing Time
Arrows
Eyes
Arrow Cued
Gaze Cued
Control

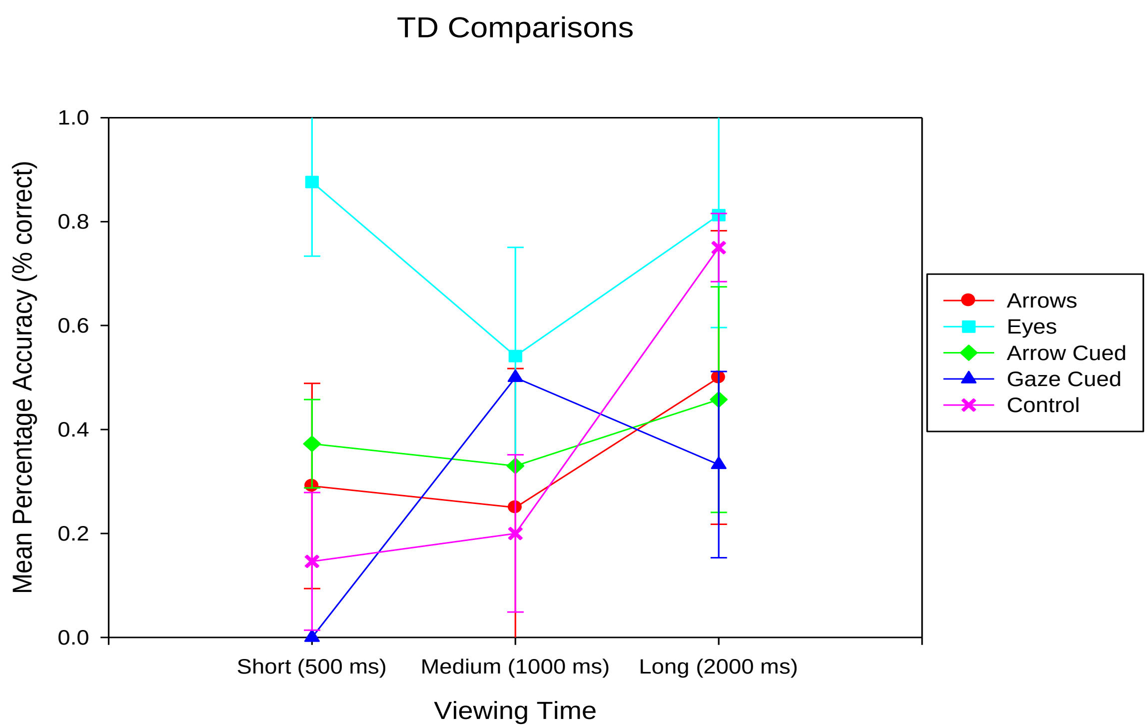


Figure 6.1. Flicker task performance results from experiment 5 for participants with a diagnosis of ASD and TD comparisons. Error bars show 95% confidence intervals.

6.2.1. AQ findings.

In TD participants, a significant correlation was found between reduced gaze-following accuracy at the medium viewing time and higher AQ scores, *r* (9) = - 0.776, *p* = .014. As the TD participants' AQ scores increased, they demonstrated less gaze-following. There were no significant correlations between AQ scores and performance for the ASD group.

6.3. Discussion

Results from 8 participants with ASD and 8 age and sex matched TD students show that social attention was generally reduced in ASD. Participants with ASD demonstrated equal overall task accuracy, confirming that change-detection is an appropriate method for investigating social attention in this population (Ames & Fletcher-Watson, 2010). As expected, participants with ASD demonstrated reduced early selection of eye-gaze and showed equally significant early selection for eyes and arrows. In contrast, TD comparisons demonstrated significant selection only for eyes at the shortest viewing interval. Therefore, participants with ASD demonstrated a lack of preference for eyes over arrows and no gaze-following. The TD participants followed gaze in patterns that mirrored previously observed (i.e. Experiment 3 & 4) pattern of moderate gaze-following at the medium viewing time, showing consistent replication of this typical pattern with the current experimental stimuli. In contrast, participants with ASD maintained fixation on the eyes across the short and medium viewing times and did not demonstrate gaze-following. ASD-like traits in the TD participants were also associated with less gaze-following. However, given the small sample-size, these results should be interpreted with caution. They are preliminary findings that require replication with a larger group of participants with ASD.

7. General Discussion

7.1. Summary of findings

Selection and orienting to gaze and arrow cues were first examined in TD young adults using four versions of the change detection paradigm (i.e. a flicker task). Given that gaze-following may be related to sociability and social competence, the Autism Spectrum Quotient (AQ) questionnaire was used to measure traits of ASD in TD participants in order to explore any relations between these traits and social attention. The task was then used to examine social attention in adolescents and young adults with ASD as compared with TD comparisons.

Experiment 1 compared singular gaze with arrow cues in order to explore whether singular cues uncover biases for social cues over non-social cues. TD adults viewed central gaze or arrow cues in otherwise identical scenes within a flicker task. Cues were not predictive of the changing object (i.e. they indicated the object only 50% of the time). TD adult participants followed gaze and arrows with equal speed and accuracy. It is possible that gaze and arrow cues may be processed equally by the human attention system. However, another possibility is that in presenting singular and central gaze or arrow cues, the current task did not force participants to reveal their attentional priorities. An additional finding was that participants who self-identified as having poorer social skills (i.e. higher levels of ASD traits) followed arrows but not gaze, suggesting that the task may have some sensitivity to traits associated with ASD.

In Experiment 2, eye-gaze and arrow cues were presented simultaneously and therefore competed for attention. The goal was to increase demands on selection in order to reveal any attentional priorities and also measure both stages of attention for eyes and arrow cues (i.e. selection and following). Participants selected eyes in a robust manner; changes to eyes were detected very quickly and accurately. Gaze-following was less robust than gaze-selection (i.e. occurred significantly slower and only during initial trials). Analysis of the first five trials showed significant initial gaze-following, which later disappeared as the task progressed. In contrast, arrows were ignored (i.e. they were neither selected nor followed). The data suggest that although there is an early bias to follow another person's eye-gaze, this can later be overridden in response to task demands. The data offer no indication that a similar bias exists for arrow following, which were never followed. Selection of eyes occurred significantly faster than gaze-following, suggesting that there may be a time course associated with social attention.

In Experiment 3, time limits where introduced, thereby increasing attentional demands to reveal the time course of selection and following for gaze. Scenes with competing gaze and arrow cues were presented for short (500 ms), medium (1000 ms), and long viewing times (2000 ms). TD adult participants then made a forced choice (i.e. yes/no) as to whether they saw a change. This task was very challenging and accuracy rates were less than 50%. A serial pattern of attention for eyes was found that was reminiscent of a joint attention response; first eyes were robustly selected (82% of the time), then often followed (57% of the time), then re-visited (84% of the time). In contrast, arrows were simultaneously selected and followed at the short viewing time. Thus, the attentional patterns for eyes and arrows were distinct. An unexpected finding was significant attention for arrows which contrasts with previous work showing that arrows are virtually ignored during real-world scene viewing (Birmingham et al., 2009a).

In Experiment 4, the role of visual salience on attention for arrows was explored. In previous experiments, the visual salience of half of the arrows had been enhanced in order to ensure that participants would attend to arrows enough to serve as a comparison cue (i.e. given that past studies show that naturally occurring arrows are ignored, arrows were made more prominent so that arrow following could be compared with attention for eyes). Possibly, this enhanced salience led to greater selection and following of arrows than would usually be the case. Thus, all highlighted arrows were returned to their original appearance. Visual saliency analyses indicated that the original arrows were significantly less visually salient than highlighted arrows and eyes were not visually salient. Performance data showed that once the visual salience of arrows was reduced, they were no longer followed; however, they were still initially selected. This may be because: arrows were recurring across scenes (i.e. participants inferred that they may be important), because they were close to text which has been shown to attract attention [(Birmingham et al., 2009a) (i.e. 12% of arrows included text, 75% were in close proximity to text)], or because arrows were objects of intrinsic interest. Gaze-following remained significant although eyes were never significantly salient. Thus, arrow-following may be mitigated by visual salience, whereas attention for gaze is likely mediated by social salience, or behavioural relevance to humans. Higher ASD traits were associated with smaller gaze selection effects, and less accurate detection of control changes at long viewing times. Three “high-scorers” on the AQ demonstrated significantly less gaze-following as compared with participants with scores in the average range.

In Experiment 5, differences in how the adolescents and young adults with ASD prioritize their attention as compared to their TD peers were examined. As compared with IQ, age and gender matched TD comparisons the 8 participants with ASD demonstrated behavioural differences at both stages of social attention. First, although participants with ASD selection gaze to the same extent as TD participants, they demonstrated no preference for eyes and were equally as likely to initially focus on eyes or arrows. Second, unlike TD comparisons, they did not follow eye-gaze at the medium viewing time. This data fits with the hypothesis that although social attention can appear superficially normal in ASD, increasing demands on selection can reveal reduced prioritization of gaze-selection (over a non-social cue) and lack of spontaneous gaze-following (Birmingham, Ristic & Kingstone, 2012). In real-life social interactions, the observed subtle attention differences may be associated with clinically significant impairments in gaze-following. However, given the small number of participants in this study, findings are only preliminary and require replication prior to further interpretation. That being said, findings of reduced gaze-selection and gaze-following align with observations from interactive lab studies (e.g. Leekam & Ramsden, 2006) and eye-tracking methods (e.g. Fletcher-Watson et al. 2009).

7.2. Implications

7.2.1. Typical Development

The first central aim of this dissertation was to clarify whether gaze-following is prioritized in adults with typical development. Theories of social attention propose that since eyes offer a good indication of another person's focus of attention, the attentional system is selective to eyes and humans will readily use eye gaze to determine where others are directing their attention (Baldwin, 1995; Baron-Cohen, 1995; Langton et al., 2000; Perrett et al., 1992). According to this view, eyes are "special" because the human attention system cares about eyes in a way that is different from other stimuli in the environment. These theories align with developmental theories that underscore the importance of joint attention in healthy human development (Mundy, 2013). However, as reviewed in the introduction, these theories have received inconsistent empirical support from lab based attention tasks. Although orienting to gaze often appears to be a priority in that it is reflexive (Friesen & Kingstone, 1998) and occurs spontaneously during a flicker task (Langton et al., 2006), a large body of research has failed to distinguish between following a gaze cue vs. following an arrow (Hommel et al., 2001; Kuhn & Kingstone, 2009; Ristic et al., 2002; Tipper et al., 2008; Tipples, 2008), throwing into question whether gaze-following is indeed "special". As an explanation, it has been suggested that eyes and arrows are artificially equated within cueing tasks, resulting in the evocation of equal behavioural responses for eyes and arrows that does not occur during "real-world" scene viewing (Birmingham et al., 2012). Certainly, data from Experiment 1 supports this notion; when gaze and arrow cues were presented centrally and singularly within a relatively simple task, no behavioural differences emerged. When eyes and arrows competed for attention, results were different. Data from Experiments 2, 3 and 4 suggests that gaze-following is uniquely prioritized by the typically developing human visual attention system, at least as compared with arrows. In these experiments, eyes were always selected and oriented to more than arrows. In fact, comparison of results from Experiments 3 and 4 indicate that participants only followed arrows when their attention was captured by the sensory properties of these arrows (i.e. arrows were bright and colourful).

Current findings offer hints as to how the human attention system prioritizes gaze-following. Theory and empirical findings are riddled with contradictions as to whether gaze-following is an innately specified reflex, a simple learned association, or a more strategic behavior (Shepherd, 2010). For example, one prominent social attention theory suggests that gaze-following is obligatory and sub-served by inborn neuro-cognitive modules (Baron-Cohen, 1995). Initial empirical findings aligned with this view - gaze-cueing appeared to be reflexive in that it occurred quickly, spontaneously, and could not be inhibited (Driver et al., 1999; Friesen & Kingstone, 1998, 2003a, 2003b; Friesen et al., 2005; Friesen et al., 2004; Langton & Bruce, 2000; Langton et al., 2000). However, careful analysis of these findings has brought into question whether orienting to gaze is truly a reflexive behavior (Wright & Ward, 2008). There are also experimental findings indicating that orienting to gaze may not be reflexive. For example, Itier, Villate, and Ryan (2007) used eye tracking to measure both gaze-selection and orienting to gaze while presenting faces to participants. Participants were asked to either determine where the eyes were looking (gaze task) or where the head was pointing (head task). While participants initially fixated on the eye-region 90% of the time, they only followed gaze 50% of the time in the head task – suggesting that orienting to gaze may be not reflexive. Aligning with such findings, current findings hint that orienting to gaze is not reflexive (although please note that reflexivity was not explicitly examined in the current study), and instead suggest that gaze-following resembles a flexible bias. Data from Experiment 2 suggests that participants had an initial bias to spontaneously follow the gaze-direction of the person within the scene. However, this bias was seemingly later overridden by strategic control; orienting to gaze no longer occurred once participants had time to determine that it did not facilitate their performance on the task. Similar to Itier and colleagues, findings from Experiments 3 - 5 suggest that early gaze-selection occurred 75-90% of the time whereas orienting to gaze occurred 40-60% of the time. The notion of orienting to gaze as a flexible behavior is consistent with the intuition that, within the context of social behaviour, people use gaze-cues in an adaptive manner to facilitate daily social communication. For example, people tend to avoid the gaze of approaching strangers in order to be polite and recent findings show that gaze-following can also be inhibited or otherwise modulated based upon the social context such as a stranger approaching or when in a large crowd of people (Gallup et al., 2012). These findings support the notion that, like gaze-following as a social behaviour, orienting to gaze is flexible to adjust to social demands.

The current data speaks to how typical gaze-selection and orienting to gaze are associated. Previously, little was known about the relationship between the two behaviours. This is likely the result to the tendency for researchers to examine the processes in isolation (Birmingham, Ristic, & Kingstone, 2012). Whereas one possibility is that gaze-selection allows for computation of gaze-direction and therefore is a prior stage (Birmingham & Kingstone, 2009), an alternate possibility is that faces/eyes and their direction are computed pre-attentively and trigger shifting of attention towards the gazed-at object without the need to initially select the eyes (Langton et al., 2006). The current data support the view that orienting to gaze relies upon gaze-selection (i.e. is a prior stage). In Experiment 2, gaze-selection occurred significantly faster than orienting to gaze. In Experiments 3 - 5 participants first preferentially focused their attention on another person's eyes and second, shifted attention towards the gaze-at object. In Experiments 3 and 4 this second stage was followed by a third stage of re-selection the eyes (although re-selection was not replicated in TD participants in Experiment 5). The stage of gaze-selection occurred faster and more frequently than orienting to gaze. This is consistent with the notion that eyes are available very early, perhaps because attention is allocated to them via a dedicated neural circuit (Pelphrey et al., 2002). Current results suggest that compared with gaze-selection, orienting to gaze is likely a later, less robust stage which likely relies upon prior analysis of gaze-direction. This is consistent with findings that eyes appear to require focused attention in order to be followed (Burton et al., 2009). In contrast, arrows do not appear to require the same initial processing; they were simultaneously selected and followed in Experiments 2 and 3.

7.2.2. ASD

The second central aim of this dissertation was to clarify whether differences at the level of visual attention associated with shifting attention in a gazed-at direction are present in ASD when orienting to gaze is measured on a computerized attention task where participants are allowed to select their visual priorities. Results from Experiments 1 and 4 suggested that traits of ASD may be related to less prioritization of eye-gaze and absent orienting to gaze. Findings from Experiment 5 confirmed differences in both gaze-selection and orienting to gaze in participants diagnosed with ASD. However, these findings must be interpreted with caution. First, there were a small number of participants in Experiment 5 so results require replication. Second, it's not clear how much flicker task performance can tell us about “real world” gaze-following. Findings suggest that, at least within a flicker task, when cognitive loading is increased (by adding the component of selection and including time constraints on a challenging task), ASD differences emerged. In terms of gaze-selection, although the groups demonstrated equivalent early gaze-selection accuracy, participants with ASD did not show preferential prioritization of eye-gaze over a non-social cue. In particular, groups did not differ in their initial prioritization of eye-gaze (i.e. selection accuracy for eye-gaze changes at the short viewing time was approximately 75% for participants with ASD and approximately 90% for TD participants). However, participants with ASD demonstrated no preference for eyes over arrows (i.e. selection accuracy for arrow changes at the short viewing time was approximately 55% for participants with ASD and approximately 35% for TD participants). These findings are consistent with others that examined unconstrained scene viewing (Fletcher-Watson et al., 2009).

Previous attention work showing subtle differences in the initial prioritization of eye-gaze during scene viewing may potentially be related to reduced prioritization of social signals over non-social signals. In contrast with previous findings from visual attention studies of reduced early gaze-selection (Fletcher-Watson, Leekam, Benson, Frank & Findlay, 2009; Freeth, Chapman, Ropar & Mitchell, 2010), current findings show intact initial gaze-selection. However, consistent with previous findings, ASD participants selected eyes and arrows to the same degree and showed reduced prioritization of eyes over non-social stimuli (Kikuchi et al., 2009). However, it is worth noting that there are likely considerable differences between the current flicker task and social interactions and current findings may not generalize to real world social interactions.

Although attentional disengagement issues are widely documented in this population and are hypothesized to partially account for social-communicative deficits (Landry & Bryson, 2004), the current data suggest that general deficits in shifting of attention/slowed disengagement do not explain the reduced gaze-following in high functioning individuals with ASD that was observed within Experiment 5. The participants with ASD were just as fast and accurate at moving their attention around the scene as their TD peers. Possibly, a specific issue with disengaging attention from faces, as opposed to a general disengagement problem could account for lack of gaze-following (i.e. data showed that ASD participants maintained their attention upon the eyes at a high rate across all three time intervals). However this is not consistent with previous work showing that participants with ASD are actually faster at disengaging attention from faces as compared with controls (Kikuchi et al., 2009) potentially reflecting less interest in faces. It therefore seems that issues with disengagement does not offer a good explanation for ASD participants maintaining their attention on the eyes instead of gaze-following in the current study.

Participants with ASD may have demonstrated lack of orienting to gaze cues because they were unable to efficiently and accurately track the person within the photograph's line of sight towards the target object in gaze-cued scenes. Leekam et al. (1997) were the first to explore whether individuals with ASD have difficulty accurately tracking eye-gaze – or precisely identify what a person is looking at. In one interactive lab experiment, they compared children with ASD's ability to spontaneously gaze-follow (*gaze monitoring task*) with their ability to accurately calculate were a person was looking upon instruction (*visual perspective taking task*). Findings indicated deficits on the gaze monitoring task but impaired performance on the visual perspective taking task was intact. Thus, participants with ASD did not spontaneously follow eye-gaze during a social interaction but were well able to accurately track another person's line of sight. In a follow-up experiment, Leekam and colleagues found that children with ASD had developmentally appropriate skills in their ability to make fine discriminations as to what object was the focus of a person's eye-gaze. These results were widely accepted as indicating that the accuracy in following line of sight was not the reason for gaze-following impairments in ASD. However, there have since been reports of impairments in accuracy of gaze-following (Pellicano, Rhodes, & Calder, 2013; Riby & Doherty, 2009; Rombough & Iarocci, 2013). For example, Rombough and Iarocci (2013) found that the children with ASD were significantly less accurate at identifying the object that a face on a computer screen was looking at when there were many (8) objects on the screen but not when fewer objects were presented (2 or 4). This finding of less accurate line of sight following when viewing object rich displays suggests that participants with ASD may struggle to accurately track line of sight when attention is taxed with multiple item displays. Problems tracking line of sight may account for current findings of absent orienting to gaze as participants were not able to accurately follow eye gaze towards the changing object on gaze-cued trials. In future research, it may be prudent to include a measure of eye-gaze following accuracy within measures of orienting to gaze in order to determine whether deficits in tracking line of sight influence performance of individuals with ASD.

Besides difficulties following line of sight, there are two other potential (and related) explanations for lack of prioritization of eyes and absent gaze-following in the ASD participants in Experiment 5. Possibly, participants with ASD may not have *recognized* eye-gaze to be an important social signal, and therefore did not prioritize it over the arrow cue. These findings are preliminary and would need to be replicated. However, if found to hold true, the finding of lack of prioritization of eyes over non-social cues has implications for theories of ASD.

7.2.2.1 Implications for theoretical understanding of gaze-following deficits

The notion that lack of gaze-following is associated with reduced appreciation of the social communicative importance of eyes fits with the social motivation hypothesis (SMH) of ASD (Dawson et al., 2005). According to this hypothesis, social deficits result from lack of motivation to engage in social behaviours (including gaze-following) because these behaviours are less rewarding to individuals with ASD. For example, whereas rewards circuits in TD brains are activated by making eye contact (Symons et al., 1998), this does not appear to be the case in ASD (Corkum & Moore, 1995; Farroni et al., 2003). According to the SMH, lack of social reward promotes reduced social motivation and over time may lead to impairments in gaze-following and joint attention (Charman, 2003; Moore et al., 1997). Computational modeling research findings align with this view and shows that reducing the reward value of eyes and faces in computer simulated “infants” results in gaze-following deficits (Triesch, Teuscher, & Deak, 2006). Lower social motivation fits with current findings that participants with ASD were equally likely to attend to eyes and arrow cues, and did not show the typical bias to follow eye-gaze.

Diminished prioritization of the eyes and less of an inclination to follow another person's eyes in early development may lead to the cascading social communicative deficits seen in ASD. Current findings align with the view that typical gaze-following is a learned or acquired skill because the behaviour appears flexible in adults and not involuntary. In contrast, gaze-selection appears to be more robust, in keeping with hypotheses that it may be present very early in development (Baron-Cohen, 1995). Taken together, these findings align with the theory that in typical human development, innate preferences for eyes likely interact with post-natal experiences to reinforce early gaze-following (Dawson, 2008; Deák et al., 2000; Müller & Carpendale, 2004; Senju & Johnson, 2009). Overtime, brain regions may become increasingly tuned to averted gaze, facilitating the development of a more specific neural network devoted to processing gaze direction (Johnson et al., 2005). Behaviorally, an innate preference for eyes likely interacts with environmental reinforcement to create a strong bias to follow another person's eye-gaze. This bias likely provides opportunity for social engagement, learning promoted by social feedback, and increased language and social cognition promoting a greater drive for social interaction and more sophisticated gaze-following. Thus, in TD, social attention may lie at the centre of a reinforcing cycle of social reciprocity and learning, whereas diminished social reciprocity and learning may ensue in children with ASD wherein gaze-following is derailed (Butterworth, 2004; Corkum & Moore, 1998; Hietanen & Leppänen, 2003; Johnson et al., 2005; Jonides, 1980; Müller & Rabbitt, 1989; Mundy, 2013).

Recently, Jones and Klin (2013) found that infants who later go on to develop ASD show the typical preference for gaze-selection at birth but then increasingly ignore eyes between 2 and 6 months of age. This suggests that although the inborn propensity to select eyes appears intact, something goes awry in the early reinforcement of social attention, causing infants with ASD to lose interest in eyes. Given the relationship between gaze-selection and gaze-following that was uncovered within Experiments 3 - 5, declines in early gaze-selection may have implications for reduced gaze-following. The answers for decline in interest in eyes may lie in structural or functional differences in the emotion and reward processing centers of the brain (e.g., amygdala, ventromedial prefrontal cortex).

7.2.2.2 Potential neuro-cognitive correlates of atypical gaze-following

Models of typical neural processing of eye-gaze information can serve as a template for conceptualizing ASD differences. For example, Senju and Johnson (2009) have proposed a theoretical model (i.e. the “fast-track modulator”) that delineates how eye contact with another person modulates activity in the structures of the social brain network that are responsible for typical gaze-following. The model proposes that low spatial frequency visual information in the form of eye contact is quickly detected by the subcortical face detection pathway. This pathway is hypothesized to include the superior colliculus, pulvinar, and amygdala structures. These subcortical structures then project to various regions of the social brain network responsible for different social tasks including perceiving gaze-direction for gaze-following (anterior STS). The mechanism underlying the processing of eye contact is fast and unconscious in that it occurs prior to cortical analysis of gaze direction. Cortical input (i.e. slow information processing from the lateral occipital cortex and inferior ventral temporal cortex) and contextual/social information then interact with input from the subcortical route to modulate processing of social information, including shifting attention to following another person’s eye-gaze towards a location/object in the environment. In other words, fast subcortical input can be influenced by top-down modulation based on task demands in the case of gaze following. This aligns with findings from Experiment 2 which suggest that participants modulated their initial biases to gaze-following after learning that gaze-following was not helpful for task performance (i.e. change-detection). In contrast, Senju and Johnson propose that selectively focusing on another person’s eyes during eye contact is associated with fast and robust neural processing. This is in keeping with findings from Experiments 2-5 of robust and early gaze-selection in TD participants. In other words, typical gaze-selection may be fast and unconscious, while typical gaze-following may be reliant upon gaze-selection and may be more susceptible to conscious (or at least cortical) modulation based upon environmental demands. With regards to ASD, Senju and Johnson offer that disrupted gaze-selection could be the result of: 1. structural impairments or abnormalities in the sub-cortex (e.g. amygdala), 2. impairments in functional connectivity between the amygdala and other brain regions, and/or 3. insufficient opportunities to learn the social meaning of gaze as a result of either structural deficits or low motivation. It is not clear which explanation fits best with current findings. However, other theories proposed by Zalla and Sperduti (2013) and Dawson et al. (2005; 2008) suggest that all three factors may interact to play a role in impaired gaze-following in ASD.

The notion that subcortical reward structures may be associated with impaired gaze-following is expanded on in a recent theory offered by Zalla and Sperduti (2013). Their “relevance detector” theory of autism proposes that an early neurological disruption of the connectivity between the amygdala and the ventro-medial pre-frontal cortex (vMPFC) disrupts the ability of individuals with ASD to flexibly shift attention towards self-relevant stimuli (e.g. eyes) over non-relevant stimuli (e.g. visually salient stimuli such as arrows). Zalla and Sperduti argue that the amgydala (along with the vMPFC) is responsible for forming a *priority map* which prioritizes self-relevant stimuli based upon either instrinsic biological significant, physical properties (i.e. visual salience) and/or the environmental context. Individuals with ASD are hypothesized to have hyper-activity of the amygdala which results in physical and emotional over arousal in response to meaningful events in the environment such as eye-contact. In particular, since the amygdala is thought to facilitate rapid and automatic bottom-up allocation of attentional resources based upon visual or biological salience, hyper-activation leads to over arousal in response to eyes. A result of this over arousal is that individuals with ASD are hypothetically less able to modulate attention (via top-down control through the vMPFC) by forming a “priority map” which allows them to regulate their focus within a social interaction. Zalla and Sperduti suggest that over arousal leads to an adaptive avoidance response which leads to reduced gaze-selection. This reduced gaze-selection, in turn, leads to reduced expertise in faces and failure to acquire joint attention. This theory offers an explanation for the current findings of equal prioritization of eyes and arrows in Experiment 5. According to the “relevance detection” theory, disruption of the relevance detection system may enhance attention orienting based upon the physical properties (e.g. visual salience) of stimuli over and above the self-relevance of stimuli. This could explain why arrows were prioritized to the same degree as eyes. However, gaze avoidance is a central prediction of Zalla and Sperduti’s theory and this does not match the current finding that participants with ASD did not avoid gaze-selection in Experiment 5. Another problem with this theory is that, as previously mentioned, there is mixed evidence of amygdala hyper-activity and/or physical and emotional over arousal in response to eye-gaze in participants with ASD (Dalton et al., 2005; Louwerse et al., 2013). Thus, the “relevance detection” theory may not offer the best fit with current findings.

In contrast with gaze avoidance, the “Social Motivation Theory” (SMT) (Dawson, 2008; Dawson et al., 2005) proposes that lack of prioritization of eyes leads to gaze-following deficits in ASD. Predictions from the SMT offer a good fit with current findings. In particular Dawson and colleague’s model clarifies how reduced activation of subcortical reward structures may leads to insufficient opportunities to learn the social meaning of eye-gaze, resulting in diminished gaze-following in ASD. Their theory posits that typical inborn preferences for eye-contact interact with environmental contingencies to reinforce early gaze-following. In typical development, neuropeptides (oxytocin and vasopressin) that are present from birth activate the dopaminergic reward system (located in the ventral pallidum, prefrontal cortex and medial amygdala). This leads to a priming of neural processing for social cues including a conditioned preference for social stimuli (faces, voices, people) within the first year of life. This preference for social stimuli is, in turn, associated with activation of the reward system including increased activation of amygdala and prefrontal cortex and anticipatory pleasures associated with social stimuli. In the second year of life, increased attention to social stimuli leads to increased development of brain regions involved in social perception and forming representations of social stimuli (including the STS, which is involved with gaze-following). There is also an increased development of integrated brain systems requiring coordination between limbic, temporal, frontal and cerebellar regions associated with joint attention, for example (i.e. shifting of attention between another person’s eyes, towards what they are viewing, and back towards the eyes). In ASD, there appears to be dampening of the rewarding effect of social stimuli (Dawson, 2008), which could be associated with decreasing attention to eye-gaze direction in early development (Jones & Klin, 2013), leading to diminished social attention and a cascading derailment of social communicative development. This fits with current findings indicating that adolescent/young adults participants with ASD did not prioritize eyes (but also did not avoid them) and then did not follow eye-gaze.

7.2.2.3. Implications for treatment of ASD

If gaze-following is the result of failure to learn that eyes are interesting and informative, early intervention may be able to reverse this learning deficit. Research shows that school-aged children with ASD can follow gaze if explicitly told to do so, but they may rarely do it spontaneously (Leekam et al., 1997). Further, these children can be trained to follow gaze through contingent presentation of rewarding visual stimuli (Landry & Parker, 2013; Leekam et al., 1998), although the sustainability of improvement has not been confirmed. The key to lasting interest in eye-gaze may lie in very early interventions that capitalize upon early brain plasticity. Recent indications of intact preference for gaze-selection at birth (Jones & Klin, 2013) suggest that early interventions aimed at sustaining or re-establishing that preference may be effective for treating ASD. In general, early intensive interventions for ASD have proven efficacy and several research groups have reported that intervention is associated with dramatic increases in functioning to the point where many children no longer appear disabled by their ASD (Baron-Cohen et al., 2001; Bayliss & Tipper, 2005; Kowler et al., 1995). Some early interventions focus upon improving the spontaneous social attention in young children with ASD by providing external rewards for gaze-selection and gaze-following (in the theoretical absence of dampened internal reward systems). For example, a recent study by Dawson and colleagues (2013) provides support for the Early Start Denver Model (ESDM) that focuses on drawing a child's attention to social stimuli. The ESDM approach aims to cultivate an intrinsic interest and liking for social stimuli (faces, eyes, voices) by consistently reinforcing a child's social engagement through play and toys. A recent randomized control trial of ESDM shows strong evidence of the effectiveness of this approach. Young children (aged 18-30 months) participated in two years of intensive ESDM intervention. As compared with children in standard early intervention approaches, the ESDM participants showed increased spontaneous social attention and associated increases in developmental level (10.6 IQ points on average), decreases in socially disruptive and repetitive behaviors, and normalized brain activity (Haith et al., 1977). Therefore, focusing behavioural interventions on increasing preferences for eyes and gaze-following has some proven efficacy for treating ASD.

Recently, there has been interest in using oxytocin nasal sprays to supplement behavioural treatment of ASD. A significant barrier to lasting treatment of social attention deficits may be low social motivation. Since social motivation may involve the neuropeptide oxytocin, there is potential for pharmacological intervention to increase intrinsic social reward. A review by Stavropoulos and Carver (2013) indicates that oxytocin shows promise, especially for increasing joint attention behaviors. Both participants with ASD and those with TD demonstrated enhanced performance on social attention tasks when administered oxytocin nasal sprays. However, further research of integrated behavioural and pharmacological treatment is needed – especially regarding the safety of such treatments.

7.3. Limitations

The current findings should be considered within the confines of this study's limitations. First, caution must be used when generalizing findings beyond the current stimuli. As similar stimuli were used across all five experiments, findings may be attributable to idiosyncrasies associated with these photographs. Efforts were made to remove and replace photographs that resulted in anomalous responding (e.g. high error rates) and to ensure that the program was running well (353 undergraduates were run in total and many of these were pilot participants). However, replication of the current results by another research group is needed before findings can be generalized beyond the current stimuli.

Another limitation of this method is that it does not allow for measurement of covert gaze-following behaviour because response times are in the seconds instead of the milliseconds. As such, it's possible that covert/reflexive gaze-following was occurring prior to the gaze-following that was measured at the 1 second (medium) viewing time in Experiments 3 - 5. It's challenging to think of a method that would be sensitive to such covert effects other than the cueing paradigm which, as discussed in Chapter 1, has several limitations in terms of ecological validity. Finally, it's possible that there are confounds associated with the flicker tasks that result in it measuring not only attention but other cognitive processes such as memory or higher order cognitive processes such as problem solving. Certainly, some research groups have moved away from the flicker task as a method for studying attention in ASD because of concerns about confounding variables (e.g. issues with disengagement; Fletcher-Waston, Leekam, Turner & Moxon, 2006). However, participants in the current study did not show signs of disengagement.

Several limitations regarding the current ASD group warrant consideration. First, diagnostic confirmation was not done with a research reliable ADI-R or ADOS. Recall that diagnosis was confirmed by one of three methods: an ADI-R on file to confirm a previous diagnosis, a psycho-diagnostic report from a psychologist or pediatrician (provincially certified to diagnose ASD), or verbal confirmation from parents that a BC standardized diagnosis was obtained in the event that the report could not be located. Although no research reliable diagnostic tests were administered, it was confirmed that each participant with ASD had received a standardized diagnosis, which includes ADI-R and ADOS by trained professionals in the province of BC. ASD symptoms were quantified using either the AQ or SRS which are not diagnostic tools but do rate the amount of ASD-like symptoms. For the participants with a lower AQ score (closer to typical), their parent was contacted to confirm their diagnostic status as well as the presence of clinically significant issues with everyday social interaction. A final limitation was that there were only 8 participants within each group in Experiment 5 which means that data may be susceptible to the influence of individual idiosyncrasies. A larger sample would need to be tested in future research. Because of the small sample size and unknown ecological validity of the current task, interpretation of findings for etiological theory and treatment of ASD in the General Discussion are purely speculative at this point in an effort to situate findings within a larger theoretical context.

7.4. Future research

Future research is needed to gain a comprehensive understanding of gaze-selection and orienting to gaze cues. Several interesting avenues for future exploration are evident. For instance, future research may aim to determine the flexibility of orienting to gaze. Current findings suggest that orienting to gaze may be less robust than previously understood. Findings from Experiments 3 - 5 suggest that orienting to gaze occurs approximately 50% of the time after gaze-selection. Experiment 2 suggests that orienting to gaze is somewhat flexible or susceptible to modulation. It would be interesting to further explore the susceptibility of orienting to gaze to top-down control. This could be accomplished by experimentally manipulating the predictiveness of gaze-cues across. For example, it would be interesting to explore whether orienting to gaze could be suppressed when cues are counter-predictive. As in the current study, orienting to gaze could be compared with gaze-selection in order to observe the relative flexibility of the behaviours. Scene viewing findings suggest that gaze-selection can be influenced by social factors such as the number of people within the scene or social tasks such as determining who is speaking (Birmingham, Bischof & Kingstone, 2008; Gallup et al., 2012; Laidlaw et al., 2011). It would be interesting to explore whether these same factors influence orienting to gaze by systematically varying the content of scenes (e.g. 1 or more people) and the task demands (e.g. “identify the speaker” or “who is the leader”?).

In future orienting to gaze research where realistic scenes are presented, investigators may wish to explicitly test ability to accurately follow line-of-sight in participants with ASD. Although current findings generally align with theories of reduced prioritization of eye-gaze in ASD and subsequent impairments in orienting to gaze/joint attention, I was not able to rule out the possibility that lack of gaze following in ASD participants was due to poor ability to discriminate the focus of another person’s eye-gaze. Future studies could include an additional task of accuracy in line of sight following which may borrow from the methodology of any previous visual discrimination task (e.g. Leekam et al., 1997; Rombough & Iarocci, 2013 .

Another interesting avenue of research may be to compare performance on the current tasks with clinical observation and measurement of social deficits associated with ASD in order to determine whether there is sensitivity to real-life social impairments in orienting to gaze. Also, neuro-imaging during task performance may provide clues as to the neural mechanisms and processes that underlie orienting to gaze deficits. Finally, it would be interesting to apply this task to treatment studies to determine if it demonstrates sensitivity to gains made during intervention. For example, the task could be completed prior to and following a nasal oxytocin spray across subjects to determine its sensitivity to potential improvements in social interest.

7.5. Concluding statement

The renowned evolutionary socio-biologist William Hamilton once wrote: “People divide roughly, it seems to me, into two kinds, or rather a continuum is stretched between two extremes. There are ‘people’ people and ‘things’ people” (2005, p. 205). Current findings suggest that, at least in terms of visual attention, typically developing participants are “people” people. They prioritized the eye-gaze of other people and then appeared to have a flexible bias to consider another person’s visual perspective. In contrast, at least within the current task, participants with ASD appeared to be equally interested in “things” as “people”. In the current study, although participants with ASD did select gaze, they did not prioritize eyes over non-social information. They also did not spontaneously orient their attention in the gazed-at direction. Hypothetically, over the course of development, reduced tendency to prioritize other people’s eyes may result in fewer opportunities to learn the social importance of gaze-following in individuals with ASD. This failure to learn joint attention may lead to a lack of neural specialization and a cascading series of social deficits. Thus, targeting early deviations from typical gaze-selection and gaze-following behavior may be a key way to effectively treat ASD and promote the social learning which relies upon sharing visual attention with another person.

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Appendix A. Autism Spectrum Quotient

The Adult Autism Spectrum Quotient (AQ)
Ages 16+

SPECIMEN, FOR RESEARCH USE ONLY.

For full details, please see:

S. Baron-Cohen, S. Wheelwright, R. Skinner, J. Martin and E. Clubley, (2001) The Autism Spectrum Quotient (AQ) : Evidence from Asperger Syndrome/High Functioning Autism, Males and Females, Scientists and Mathematicians Journal of Autism and Developmental Disorders 31:5-17

Name:.. Sex:..

Date of birth:.................................. Today's Date................................

<u>How to fill out the questionnaire</u>

Below are a list of statements. Please read each statement <u>very carefully</u> and rate how strongly you agree or disagree with it by circling your answer.

DO NOT MISS ANY STATEMENT OUT.

Examples

E1. I am willing to take risks.	definitely agree	slightly agree	slightly disagree	definitely disagree
E2. I like playing board games.	definitely agree	slightly agree	slightly disagree	definitely disagree
E3. I find learning to play musical instruments easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
E4. I am fascinated by other cultures.	definitely agree	slightly agree	slightly disagree	definitely disagree

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree

17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is disturbed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree
27. I find it easy to "read between the lines" when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don't usually notice small changes in a situation, or a person's appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I'm not sure when it's my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree

34. I enjoy doing things spontaneously.	definitely agree / slightly agree / slightly disagree / definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree / slightly agree / slightly disagree / definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree / slightly agree / slightly disagree / definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree / slightly agree / slightly disagree / definitely disagree
38. I am good at social chit-chat.	definitely agree / slightly agree / slightly disagree / definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree / slightly agree / slightly disagree / definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree / slightly agree / slightly disagree / definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree / slightly agree / slightly disagree / definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree / slightly agree / slightly disagree / definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree / slightly agree / slightly disagree / definitely disagree
44. I enjoy social occasions.	definitely agree / slightly agree / slightly disagree / definitely disagree
45. I find it difficult to work out people's intentions.	definitely agree / slightly agree / slightly disagree / definitely disagree
46. New situations make me anxious.	definitely agree / slightly agree / slightly disagree / definitely disagree
47. I enjoy meeting new people.	definitely agree / slightly agree / slightly disagree / definitely disagree
48. I am a good diplomat.	definitely agree / slightly agree / slightly disagree / definitely disagree
49. I am not very good at remembering people's date of birth.	definitely agree / slightly agree / slightly disagree / definitely disagree

50. I find it very easy to play games with children that involve pretending.	definitely agree / slightly agree / slightly disagree / definitely disagree

Developed by:
The Autism Research Centre
University of Cambridge

Appendix B. Sample stimuli from Experiments 2-5

Arrow-Changes (measuring selective attention for arrows)

Eye Changes (measuring selective attention for eyes)

Arrow-Cued Changes (measuring arrow following)

Gaze-Cued Changes (measuring gaze-following)

Control Changes (measuring baseline change detection time and/or accuracy)

Filler trials (included to make experimental aims less obvious to viewers)