WHAT'S ODD? COGNITIVE PROCESSING OF SOCIAL CONTEXTS BASED ON AUTISTIC TRAITS WITHIN THE GENERAL POPULATION

by

Louisa Lok Yee Man

A thesis submitted to the Department of Psychology

In conformity with the requirements for

the degree of Master of Science

Queen's University

Kingston, Ontario, Canada

(October, 2018)

Abstract

Autism Spectrum Disorder (ASD) is a neurodevelopmental disorder characterized by social and communicative deficits, such as being able to identify and understand a joke. These social deficits can be understood in a cognitive framework; smaller differences in perceptual processing can snowball into tangible larger differences in complex and dynamic social situations (Benson, Castelhano, Howard, Latif & Rayner, 2016; Minshew & Goldstein, 1998). For example, individuals with ASD have a greater difficulty with tasks requiring higher-order or complex cognitive processing (Minshew & Goldstein, 1998; Benson et al., 2016). The present study extends prior research examining ASD-like cognitive processing styles in non-clinical individuals by examining how different levels of ASD-like traits in the general population can affect perception of social contexts (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Ruzich et al., 2015). ASD-like traits were measured by the Autism Quotient (AQ; Baron-Cohen et al., 2001). Participants completed a visual/social oddity task that varied on whether complex or simple processing of a visual scene was required. Scenes could be visually odd (e.g., girl with a vase as a "third leg," which requires simple re-parsing of visual features, or socially odd (e.g., a man walking a lettuce on a leash), which requires integration of past knowledge of social norms. If ASD-like traits are linked with impaired complex but not simple processing we expect people with high ASD-like traits to show differing eye movement patterns for socially odd (complex) but not visually odd (simple) stimuli, with no differences for those with low traits. No significant interactions or main effects were found for differing levels of ASD-like traits.

Acknowledgements

First and foremost, thank you to my supervisor, Dr. Monica Castelhano, for your endless support and guidance throughout my degree. Thank you for never hesitating to take time out of your busy day for our countless long meetings where we ironed out issues or talked about exciting new ideas.

To my committee members, Dr. Meredith Chivers and Dr. Jill Jacobson: thank you for your endless support throughout the entirety of this project and for providing your expertise on numerous aspects of this project. To Dr. Chris Bowie, thank you for scaffolding my theoretical understanding of the debate between categorical and dimensional conceptualizations of diagnoses. To Dr. Tess Clifford, thank you for the opportunity to work with children with ASD and for the many discussions we have had about the theories of ASD throughout my practicum placement.

To QVCL: thank you for making even the windowless portion of the lab the sunniest place to work and of course, thank you for your tireless and efficient data collection. Thank you to Elysée Kukwabantu and Mollie Roy for your help in managing participant recruitment and prescreening. Thanks especially to Shane Kennedy for always fixing our Matlab scripts for data analysis and providing programming support wherever and whenever needed.

To my friends: thank you for your continued support despite the fact I seem to have been talking ceaselessly about this thesis for what seems like the past century. Thank you to Meghan McInnis and Ellen O'Donoghue for letting me bounce ideas off of you while showing me the best (noodles) that Kingston has to offer. Thank you to Nelly Matorina, Mahdiah Lakhani, Erin Tobin, Fiona Lo and Nagia Bobotsis for the endless stream of encouraging messages, fresh memes and absurd gifs that got me through the various stages of my thesis. To Leo Chan, thank you for the delicious banana bread.

Finally, I would like to thank NSERC and Queen's University for providing the grants that supported this project.

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List of Abbreviations

AQ – Autism Spectrum Quotient

ASD – individuals with Autism Spectrum Disorder

BAP – Broader Autism Phenotype

CIP – Complex Information Processing Theory

EPF – Enhanced Perceptual Function Theory

TD – Typically Developing individuals

WCC – Weak Central Coherence Theory

Chapter 1

Introduction

One in 68 North Americans are affected by Autism Spectrum Disorder (ASD), a neurodevelopmental disorder characterized by social deficits, repetitive behaviours and communication deficits (American Psychiatric Association, 2013; Baio, 2018). Researchers have attempted to capture differences in one of these core features, social deficits, by understanding the underlying cognitive differences between individuals with ASD and typically developing (TD) individuals (Happé & Frith, 2006; Minshew & Goldstein, 1998; Mottron et al., 2006). By doing so, researchers can look at how small differences in cognitive processing can lead to a tangible impairment in a fast and dynamic social interaction (Benson, Castelhano, Howard, Latif & Rayner, 2016). Even a slight increase in processing time due to needing multiple fixations to process a social cue can add up to a noticeable delay in social response when multiple social cues need to be integrated (Benson et al., 2016).

Comparing ASD and TD groups is consistent with the categorical approach of understanding neurodevelopmental disorders, where clinical and non-clinical populations are described as qualitatively distinct (Brown & Barlow, 2005; Widiger & Samuel, 2005). However, recent research suggests that similar underlying cognitive patterns have been found in non-clinical individuals: with individuals presenting high or low levels of autistic traits (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Ruzich et al., 2015). This raises the question of whether clinical and non-clinical populations may overlap in the underlying distribution of cognitive processing traits, and clinical populations simply representing extreme cases in a normal distribution. In line with this notion of dimensional variation in autistic traits, we were interested in examining whether there were differences in underlying cognitive patterns in processing social contexts between TD individuals with high or low levels of autistic traits.

1.1 Cognitive Underpinnings of Social Impairment in ASD

Several theories examine how underlying cognitive differences can lead to downstream social deficits in individuals with ASD. The Complex Information Processing Theory (CIP) posits that social impairments arise from differences in underlying cognitive processing (Minshew & Goldstein, 1998; Minshew, Williams & McFadden, 2009). Further, theorists posit that social impairments are due to impaired cognitive processing of complex but not simple information (Minshew & Goldstein, 1998). Minshew and colleagues used neuropsychological batteries to characterize the cognitive profile of ASD individuals with high cognitive function (i.e., IQ > 80) (Minshew, Goldstein & Siegel, 1997; Minshew & Goldstein, 1998). Across studies, complexity of information processing has been defined in different ways. For instance, it could be defined by the number of items an individual has to manipulate when processing information or by the number of processes involved. Examining the conceptual reasoning domain, Minshew and Goldstein (1998) found that individuals with and without ASD performed similarly on simple tasks that rely on the application of one or two simple rules, like the Wisconsin Card Sorting Task. However, ASD individuals were impaired on more complex tasks like the Twenty Questions task. This task is more complex because it requires an individual to narrow down an infinite number of possibilities by applying continual, evermore constraining questions. The type of constraining question required is dynamic and changes with each new piece of information from each answer. Thus, the CIP explains social and behavioural differences of individuals with ASD based on deficits in complex but not simple information processing (Minshew & Goldstein, 1998).

Within the visuospatial domain, other prominent cognitive theories of ASD are compatible with the CIP (Happé & Frith, 2006; Mottron et al., 2006). Through the Weak Central Coherence theory (WCC), Happé and Frith (2006) posit that there is a core deficit in extracting global meaning. A common task used to investigate this theory is the Navon task, using stimuli that have smaller letters that are arranged to form a larger letters (see *Figure 1a*). To investigate global and local processing, both individuals with ASD and TD individuals were asked to identify either the larger letter (global processing), or the smaller letter (local processing). Individuals with ASD show greater impairment than TD individuals at naming the global letter if local letters are incongruent. Thus, individuals with ASD were more susceptible than TD individuals to interference from local information (Rinehart, Bradshaw, Moss, Brereton & Tonge, 2000). This impairment in global integration of information is consistent with the CIP, where ASD individuals are not impaired when processing the smaller details but are impaired when a task requires the integration of a larger number of these smaller details, increases the complexity of information processing (Minshew & Goldstein, 1998).

Figure 1. Navon figure and featural-configural task stimuli examples.

a) Navon Figure: a larger letter (H) is formed by smaller letters (T), b) The featural task includes shapes with no overlapping features so a single feature can be used to distinguish it from the rest. The configural task includes one overlapping feature with another shape (e.g., two blue shapes, two circles), so a single feature strategy cannot be used to distinguish between shapes and a configural strategy should be used. Stimuli from Plaisted et al. (2003) study.

Another cognitive theory of visuospatial processing is the Enhanced Perceptual Functioning theory (EPF; Mottron et al., 2006; Plaisted, Saksida, Alcantara & Weisblatt, 2003). This theory posits that individuals with ASD are better at local-oriented tasks than global-oriented tasks due to an enhanced perceptual system. For example, ASD individuals performed better than TD individuals at a featural discrimination task, whereas no difference was found in a configural task (Plaisted et al., 2003). In the featural task (see *Figure 1b*), participants were asked to press the left button when a pink star or an orange square appeared on screen and the right button if a yellow triangle or purple cross appeared on the screen. Shapes could be distinguished by a single feature (e.g., associating the colours to the left button or associating the shapes with the right button). In the configural task, the blue bar and red circle was associated with the left button and the red bar and blue circle were associated with the right button. In this task, the same strategy of using one feature (i.e., “if blue, press left button”) cannot work because the same feature is used for both button responses. Thus, the configural task requires a more global representation, binding shape and colour into unique representations.

Whereas the WCC posits that ASD individuals have a deficit in global processing and are not different from TD individuals in local processing, the EPF posits an enhancement of local processing at no cost to global processing (Happé & Frith, 2006; Mottron et al., 2006). However, these theories both describe a similar processing difference where individuals with ASD are better at processing local than global visual information. This is compatible with the CIP (Minshew & Goldstein, 1998), where ASD individuals perform better at simple processing (e.g., featural tasks that require processing of only one piece of information) than complex processing (e.g., configural tasks that require integration of multiple features: shape and colour). Because of its compatibility and its broader understanding across multiple domains (including the social interaction domain), we will use the CIP as the main theoretical framework of the present study.

Consistently, Pierce, Glad and Schreibman (1997) also have found that social impairments in ASD individuals can be explained by an underlying cognitive deficit. Pierce et al., (1997) had children with and without ASD viewed video vignettes of two children interacting. These video vignettes varied in the number of social cues that led to a correct interpretation of the scene (including tone content, nonverbal cue, nonverbal with object). Children with ASD performed at the same level as TD children when interpreting vignettes that could be understood with one social cue. However, children with ASD performed significantly worse for vignettes that required integration of multiple cues. The authors concluded that rather than a deficit in processing social cues, individuals with ASD were impaired at integrating multiple cues more generally.

In a recent set of studies, Benson and colleagues investigated underlying cognitive differences between TD and ASD individuals when processing real-world, complex scenes (Benson et al., 2012; Benson et al., 2016). To test the CIP theory where ASD individuals are impaired at processing simple but not complex tasks (Minshew et al., 1998), Benson et al. (2012) had participants complete the *spot the difference* task and *which one's weird* task, each assessing simple or complex processing respectively; the complex task was designed to require additional integration of a priori knowledge above and beyond the perceptual processing required to complete the simple task. Although ASD individuals did not differ from TD on the simple task, Benson et al. (2012) found that on the complex task, ASD individuals do not immediately detect oddities within scenes. Moreover, Benson et al. (2012) find in a post-hoc analysis that ASD were slower to respond when scenes had social content whereas no such differences was found for TD individuals. Thus, Benson et al. (2012) provide evidence to support CIP, where ASD show behavioural and cognitive differences from TD individuals in processing stimuli that contain social content.

In a subsequent study, Benson et al. (2016) asked ASD and TD individuals to view scenes that were either visually or socially odd while eye movements were recorded. With visually odd scenes, participants initially grouped features erroneously, which led to an odd interpretation of the scene (see *Figure 2a-b*). To interpret the scene properly participants had to regroup visual features correctly. Identifying socially odd scenes required participants to integrate prior social knowledge – a more complex task (see *Figure 2c-d*). Benson et al. (2016) found that although ASD individuals were just as accurate as individuals without ASD at identifying whether a scene was odd, eye movement patterns reflected different cognitive processing across groups and scene types. First, they found that ASD individuals were impaired at initially detecting the odd region in the socially but not visually odd scenes, taking longer to identify social oddities. Second, ASD individuals were more likely to revisit the odd regions multiple times before responding. Together, these eye movement data can be used to infer subtle differences in information processing – that ASD individuals failed to identify critical information at first glance and require more time to process that information overall. According to CIP, because ASD individuals have difficulty with complex processing in the cognitive domain, these subtle processing differences could snowball into tangible social impairments in fast, dynamic interpersonal interactions.

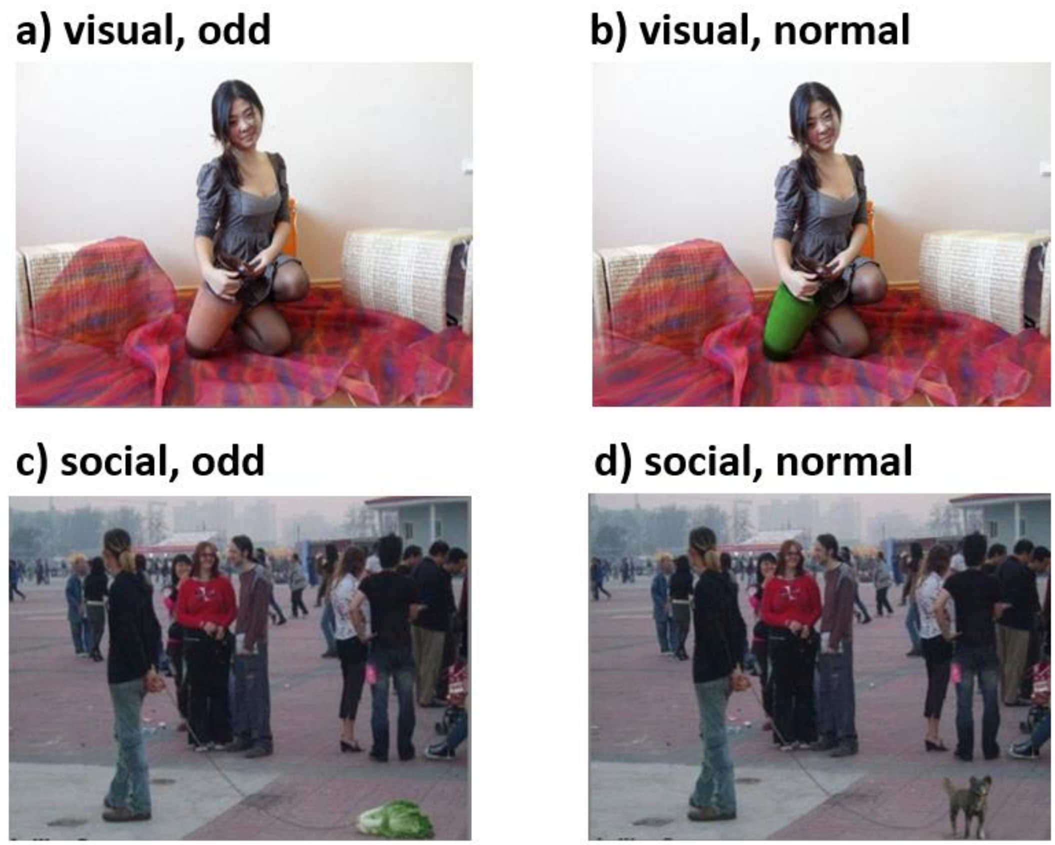

Figure 2. These examples are stimuli used in the study, taken from Benson et al. 2016. a) An example of a visual oddity, where an accidental visual grouping of the vase and the woman's two legs can lead to the erroneous and odd interpretation that the woman has three legs; b) The normal counterpart of the visually odd stimuli, edited so that the vase has a distinctive colour to prevent erroneous visual grouping. c) A socially odd scene, where someone is violating social convention by appearing to 'walk a cabbage' as if it were a pet; d) shows the normal counterpart of the socially odd stimuli, with a dog edited in place of the cabbage to be consistent with social expectations. For the full set of stimuli, see Supplementary Information found in Benson et al., 2015.

1.2 ASD: a cognitive spectrum

Researchers have previously characterized ASD in a categorical framework, distinguishing between clinical and non-clinical populations as qualitatively different. This is contrasted with the dimensional framework of clinical disorders, where traits are understood as a continuum (Brown & Barlow, 2005; Widiger & Samuel, 2005). One limitation of the categorical framework is the ability to define categories that represent distinct disorders (Widiger & Samuel, 2005). For example, Walker et al. (2004) describe three subgroups of Pervasive Developmental Disorder Not Otherwise Specified (PDD-NOS), which are considerably like ASD. Many subgroups show considerable overlap with ASD traits: One subgroup is like high functioning ASD but with greater language impairment, another subgroup is like low functioning ASD but with fewer stereotyped behaviours, and a third subgroup has a later onset of ASD-like traits. Additionally, there is also considerable overlap between Social Pragmatic Communication Disorder (SPCD) and ASD, which is a disorder with similar core social and communicative impairments in absence of restrictive behaviours (Norbury, 2013; Swineford, Thurm, Baird, Wetherby & Swedo, 2014). The high overlap of ASD traits with other disorders has led many researchers to re-examine the use of categories to define ASD, and posit that an alternative framework like a dimensional approach might be useful.

In addition to unclear boundaries, there is a question of distinctiveness between clinical and non-clinical ASD populations. ASD has been established as a heritable disorder, where family members of someone with ASD are more likely to be diagnosed with ASD (Bourgeron, 2016; Sandin et al., 2014). Moreover, family members of individuals with ASD are also more likely to have subclinical levels of ASD-like traits, such as mild social cognition impairment and more stereotyped behaviours (Bishop, Maybery, Wong, Hill & Hallmayer, 2004; Losh, Adolphs & Poe, 2009; Piven, Palmer, Jacobi, Childres & Arndt, 1997; Wheelwright, Auyeung, Allison & Baron-Cohen, 2010). This is referred to as the Broader Autism Phenotype, where the milder levels of ASD-like traits found in family members of ASD individuals form a continuum below the clinical threshold. The distinguishing factor of clinical group is the degree to which daily functioning is impaired enough to warrant a diagnosis. In twin pairs, individuals with a twin who has ASD have more subclinical social and language impairments than individuals whose twin does not have ASD (Le Couteur et al., 1996). This effect is stronger for monozygotic (who share more genes) than dizygotic twins, indicating that genetic heritability is a factor in influencing subthreshold levels of ASD-like traits. The Broader Autism Phenotype posits that there is a spectrum of ASD-like behaviours, as evidenced by milder but qualitatively similar traits for individuals with a family history of ASD.

Several measures have been developed to capture the dimensionality of ASD-like behaviours (Baron-Cohen et al., 2001; Hurley, Losh, Parlier, Reznick & Piven, 2006). The Broader Autism Phenotype Questionnaire is a measure aimed at capturing variation in ASD-like traits in parents with children who have ASD (Hurley, Losh, Parlier, Reznick & Piven, 2006). The Autism Spectrum Quotient (AQ) further investigates the spectrum of behaviours beyond the Broader Autism Phenotype by capturing ASD-like traits that occur in the general population, regardless of family history of ASD (Baron-Cohen et al., 2001). By quantifying ASD traits as a spectrum, we were able to investigate the cognitive factors that contribute to ASD-like behaviours.

Understanding how the continuum of ASD-like behaviours can be understood as the outcome of different cognitive processes is useful for several reasons. First, it can give us a more nuanced understanding of heterogeneity within the ASD diagnosis (Dworzynski, Ronald, Bolton & Happé, 2012). Second, the continuum can help us understand how ASD-like cognitive processing could give rise to individual differences in social skills across the general population.

The DSM-V describes ASD as a heterogeneous disorder with a considerable amount of variations within the clinical population, coherent with the idea of a spectrum of variable levels of autistic traits (American Psychiatric Association, 2013). For example, if social deficits in ASD arise from differences in underlying cognitive processing (Minshew & Goldstein, 1998), we can examine how this degree of impairment in complex processing works in tandem with learned social strategies to produce behavioural variation. An individual with a high degree of complex processing impairment but also good social strategies could function better in daily life than someone with a lesser degree of impairment with poor social strategies. We can further extend this continuum of underlying cognitive differences to non-clinical individuals (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). Examining the full range of ASD-like cognitive processing in the general population can inform us of alternative strategies that allow non-clinical individuals to function adaptively in social contexts despite underlying cognitive differences.

Additionally, extending the ASD continuum to include non-clinical individuals allows us to investigate whether cognitive theories of social functioning, such as the CIP, could be applied more broadly to understand individual differences (Minshew & Goldstein, 1998). Numerous studies have investigated whether individuals with ASD-like cognitive processing also show similar social deficits when compared to individuals with less ASD-like cognitive processing (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al. 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). These studies typically use the non-diagnostic AQ as a tool to quantify ASD-like traits (Baron-Cohen et al., 2001). The AQ is composed of subscales that allow for the characterization of specific ASD-like traits, including poor social skills and repetitive behaviours, which have previously been found in individuals as part of the Broader Autism Phenotype (Losh, Adolphs & Poe, 2009; Piven, Palmer, Jacobi, Childres & Arndt, 1997). The original AQ was designed with five subscales that examine social skill, attention switching, attention to detail, communication and imagination (Baron-Cohen et al., 2001). Factor analyses commonly support three factors: social interaction, attention to detail and poor communication (Austin, 2005; Hoekstra et al., 2008; Hurst et al., 2007). These three sub-scales coincide with the three core symptoms of ASD, including social impairment, increased attention to details rather than holistic (e.g., WCC, EPF) and communication impairment. Because the AQ has been validated for use in the general population, this measure will help us identify ASD-like traits for individuals not included in the Broader Autism Phenotype as well. In the current study, we are interested in investigating the full ASD continuum, inclusive of individuals who may fall into clinical (i.e., diagnosed ASD), subclinical (i.e., Broader Autism Phenotype) or non-clinical groups (i.e., no diagnosis).

Researchers have found that non-clinical individuals who have a higher AQ score (high AQ) reflect a similar cognitive pattern as individuals with ASD (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). Relative to low AQ individuals (i.e., fewer ASD-like traits), individuals with high AQ (i.e., more ASD-like traits) were poorer at a social cueing task that required following another's gaze (Bayliss & Tipper, 2006; Fletcher-Watson et al., 2009; Ristic et al., 2007). In terms of perceptual processing, studies have shown that high AQ individuals had more difficulty with global identification of Navon figures (Figure 1a), but were faster in the embedded figures task (Grinter et al., 2009; Sutherland & Crewther, 2010). The latter task requires local processing of details in order to find an embedded figure among a pattern of other lines (see Figure 3; Damarla et al., 2010). These patterns of results suggest that a high AQ is associated with more difficulty processing complex information at a more global level. Moreover, Stevenson and colleagues (2016) found that those with higher scores on the attention to detail subscale of the AQ were better at completing the Navon task and composite face task when local processing was needed to complete the task. Together, these studies are consistent with the CIP and suggest that this theoretical framework can be more broadly applied to understand social behaviours in the general population.

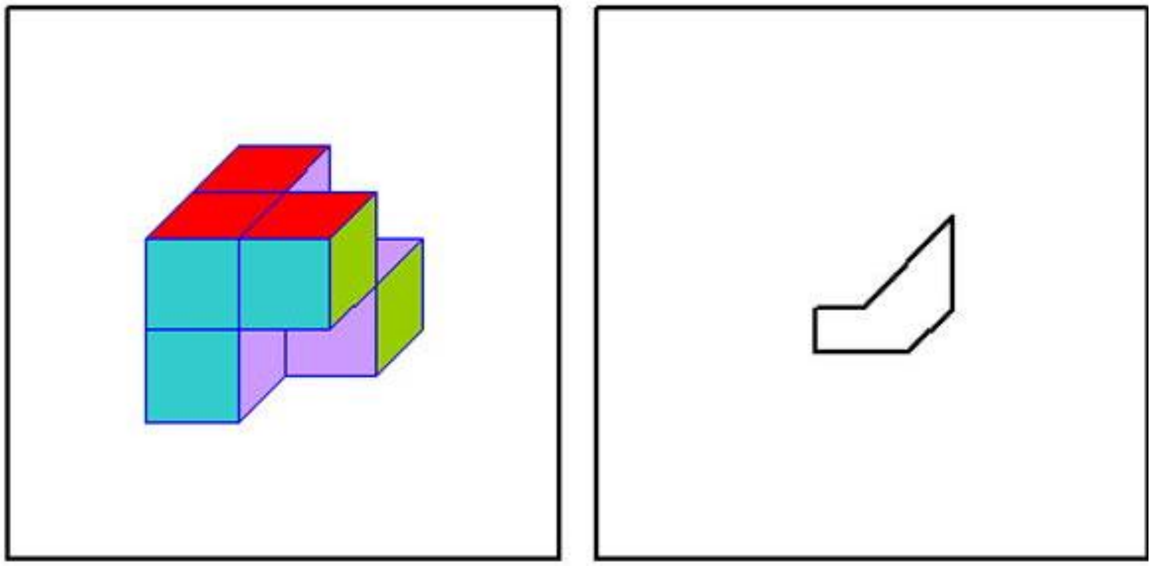

Figure 3. This is an example of the Embedded Figures Task, where participants are asked to find the shape outline on the right side in the figure on the left (Damarla et al., 2010); here, the critical outline can be found surrounding the purple and green surfaces at the back lower right of the figure.

1.3 The Current Study

The present study's goal was to identify whether underlying cognitive differences contribute to downstream social impairments on the ASD continuum. We investigated whether individuals in the general population with high and low levels of ASD-like traits varied in the cognitive processing of social contexts (Minshew & Goldstein, 1998; Pierce et al., 1997). This is consistent with the dimensional framework of understanding how traits commonly associated with ASD are also found in the Broader Autism Phenotype (Bishop et al., 2004; Losh et al, 2009; Piven et al., 2010) as well as the general population (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). Moreover, the present study further investigated how cognitive processing styles can underlie differences in processing of social contexts.

To capture the dimensional nature of ASD-like traits in the general population, we used the AQ (Baron-Cohen et al., 2001) and identified individuals with high or low levels of ASD-like traits. Participants were asked to complete the visual/social oddity paradigm (Benson et al., 2016) while their eye movements are recorded. In the visual/social oddity paradigm, individuals were asked to identify whether a scene was odd. Scenes could be either visually odd (e.g., visual illusion where a vase is mistaken for a woman's third leg) or socially odd (e.g., a man "walking" a cabbage). These tap into differing levels of complexities in scene processing (Minshew & Goldstein, 1998). Identifying visually odd scenes required simple processing by regrouping low-level visual information (Parkkonen, Andersson, Hämäläinen & Hari, 2008). Identifying socially odd scenes required a more complex process of integrating learned social conventions with the scene's visual details to identify the oddity. In sum, the current study examined whether individuals with high or low ASD-like traits show similar cognitive patterns when processing scenes in a low or high complex task.

Consistent with past research that investigated the ASD on a continuum, we expect to replicate the effects found in comparing clinical and non-clinical groups (Benson et al., 2016).

However, because we compared individuals within the non-clinical population, we expected smaller effect sizes than when comparing between clinical and non-clinical groups (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). This supports the notion that ASD-like traits are found both in the Broader Autism Phenotype and general population such that clinical and non-clinical individuals are distinguished by a bimodal distribution (Skuse, Mandy & Scourfield, 2005). If cognitive processing differs, we expected individuals with high ASD-like traits to respond slower than individuals with low ASD-like traits; however, this difference will be smaller than comparing clinical and non-clinical groups. To examine underlying cognitive processing of scenes, we analyzed eye movements that fall within the defined region of interest (ROI) – the region of the oddity in the scene. For these ROIs, we calculated measures that reflected both early and later cognitive processes. For early measures, when participants' eyes first land within the ROI, we expected low AQ individuals to process visual and social oddities similarly and hence have similar initial fixation durations. We expected high AQ individuals to spend less time initially processing social oddities than visual oddities. This shorter early processing of social oddities would indicate that individuals with high ASD-like traits were not detecting the social oddity at first glance. In late processing measures, we predicted individuals with high ASD-like traits had longer inspection times, higher number of revisits, and longer fixation measures than individuals with low ASD-like traits.

Chapter 2

Experiment

2.1 Description of Study

Method

Participants

The original sample size of 168 was determined (84 in each experimental group) through a power analysis using the pwr package in R (Champely et al., 2018; R Core Team, 2013). This analysis was based on the effect size (*d* = .65) reflecting the difference between ASD and TD on the initial processing time (Benson et al., 2016). We calculated 90% power at $\alpha = .05$. A conservative small to moderate range of effect sizes (*d* = .30 to .50) was used to accommodate for the smaller effect size expected when comparing groups within the general population. A range of sample size of 85 to 234 was obtained. If the true effect is a small effect size (*d* = .30), this sample represents 47% power; if the true effect is a moderate effect size (*d* = .50), this sample represents 87% power. The full sample size was not reached because of recruitment and time constraints.

A total of 77 participants were recruited for this study from the first-year psychology course and surrounding Kingston community for course credit or $10 compensation. A total of 34 participants with high autistic traits (27 female, 7 male) and 43 participants with low autistic traits (36 female, 7 male) were recruited for this study (see Table 1 for a summary of demographic information). High and low autistic trait groups were determined by a threshold of one standard deviation above (an AQ score of 24 or more) and below (an AQ score of less than 13) the mean scores on the AQ obtained as part of set of prescreening questionnaires ($n = 3170$, $M = 18.12$, $SD = 5.94$).

To identify whether additional factors may affect interpretation of the AQ scores, we obtained participant responses to the Big Five Inventory (BFI) questionnaire and Beck Depression Inventory (BDI) from the prescreen database for the 70 participants who were recruited through the prescreening process (Beck et al., 1961; John & Srivastava, 1999). High and low AQ groups significantly differed on the Big Five personality traits of extraversion ($t(68) = -6.10$, $p < .01$), agreeableness ($t(68) = -3.66$, $p < 0.01$), neuroticism ($t(68) = 5.39$, $p < .01$) and openness ($t(68) = -3.11$, $p < .01$). There were no significant differences on the Big Five trait of conscientiousness ($t(68) = .13$, $p = .90$). There was also a significant difference between AQ groups on the BDI, a depression screening measure, $t(68) = 2.88$, $p < .01$. No quantitative measure of anxiety was administered; three participants reported a diagnosis of generalized anxiety disorder, but all were part of the low AQ group.

Table 1

Summary of demographic information by experimental group.

	Total		High AQ		Low AQ	
	M	*SD*	*M*	*SD*	*M*	*SD*
Age (years)	18.77	1.49	18.76	1.28	18.77	1.65
Years of education	13.44	1.87	13.18	2.35	13.64	1.37
AQ score	17.48	10.51	28.82	3.36	8.51	2.11
BDI score	8.75	8.95	12.26*	9.20	6.03*	7.82
BFI scores						
Extraversion	26.77	7.30	21.94	6.62	30.62	5.29
Agreeableness	34.90	5.70	32.32*	5.70	36.95*	4.87
Conscientiousness	32.16	5.76	32.26	6.56	32.08	5.12
Neuroticism	27.01	6.96	31.29*	5.63	23.70*	6.06
Openness	34.39	6.07	32.00*	6.55	36.28*	4.97

Significance at $p < .05$

Materials

All reported Cronbach's α values below were calculated for sample collected in this study.

Autism Spectrum Quotient (AQ). This non-diagnostic measure included 50 questions (Cronbach's α = .93) that assessed for different autistic-like traits present in the general population (Baron-Cohen et al., 2001). The scale had five subscales, which assessed for social skill, attention switching, attention to detail, communication and imagination. Participants were asked to respond whether they definitely agree, slightly agree, slightly disagree or definitely disagree to statements such as "I prefer to do things with others rather than on my own." A higher AQ score indicated that an individual has endorsed more ASD-like traits. Although this was a diagnostic tool, individuals with diagnosed high functioning ASD typically score above 32 on this measure.

Beck Depression Inventory (BDI). This 21-item questionnaire (Cronbach's α = .92) was a screening measure for characteristics of depression (Beck et al., 1961). In each question, participants were asked to select the statement that applies to the experience they had in the past two weeks the most, for example, "I do not feel sad," "I feel sad," "I am sad all the time and I can't snap out of it," and "I am so sad or unhappy that I can't stand it." A higher score indicated that an individual endorsed more statements related to depression.

Big Five Inventory (BFI). This was a 44-item questionnaire that assesses five major personality traits, including the extraversion (Cronbach's α = .86), agreeableness (Cronbach's α = .75), conscientiousness (Cronbach's α = .78), neuroticism (Cronbach's α = .84) and openness (Cronbach's α = .71) subscales (John & Srivastava, 1999). Participants were asked to respond whether they disagree strongly, disagree a little, neither agree nor disagree, agree a little or agree strongly to various statements such as "is full of energy," or "is generally trusting," etc.

A high score in openness to experience subscale indicated that individuals were more curious or inventive. A high score on the conscientiousness subscale indicated that an individual was efficient and organized. One hallmark of ASD is the need for consistent routine, so the people with high AQ also may score lower on openness to experience and higher on conscientiousness subscales of the BFI. A high score on the extraversion subscale indicated that individuals were outgoing whereas a low score described someone who was more reserved. A high score on the agreeableness subscale indicated more friendliness, whereas a low score indicated more detachment. An individual with a high AQ because of social impairments may score lower on the extraversion and agreeableness subscales (Jobe & White, 2007). Finally, a high score on the neuroticism subscale indicated that an individual was sensitive or nervous whereas a low score would indicate that they are secure or confident. Past research has suggested that ASD and other anxiety disorders are often comorbid (Piven & Palmer, 1999); high AQ individuals might score higher on the neuroticism scale.

Stimuli. Stimuli were displayed 475 pixels by 360 pixels, with images subtending a visual angle of 22.4° X 17.40°. For this task, scenes belonged to one of two picture types: visually odd or socially odd pictures (see *Figure 2*). Visual oddities were pictures that violate physical norms; for example, someone in the picture appears to have a third leg. Social oddities were pictures that violated social norms; for example, someone walking a lettuce on a leash. All scenes were taken from Benson et al. (2016), which included a validation by a separate group of participants who judged these scenes as odd. There was a total of 96 scene stimuli; half the scenes were socially odd, and the other half were visually odd (picture type). For each scene, there were two versions: a normal version and an odd version.

Eye Movement Recording. Eye movements were sampled at 1000 Hz using an Eyelink tracker on the right eye (S.R. Research Ltd, Canada) while viewing was binocular, consistent with past studies investigating eye movement patterns in ASD (Aitkin, Santos & Kowler, 2013; Benson et al., 2015). Participants sat 60cm away from the 21-in. CRT display monitor. Participants used a chin rest and forehead support to stabilize their head position.

Procedure

Participants were recruited based on their AQ scores, obtained as a part of a prescreening package prior to recruitment. After obtaining informed consent, participants first completed the oddity task while eye movements were tracked. Participants were given these verbal instructions: "Please determine whether the following scenes are odd or not via button press". Whether the yes/odd button appeared on the left or right of the button box was counterbalanced across participants. Participants were also given examples of odd scenes (including visually and socially odd scene examples) to familiarize themselves with the task.

We calibrated participants' eye movements using a 9-point matrix. Prior to each trial, calibration was checked, and recalibration was done as needed. Participants were shown a five-point calibration before a fixation cross appeared either to left [located at (300px, 200px) from top left corner] or right side [located at (300px, 600px) from top left corner] of the screen. When the participant fixated on the fixation cross, the scene would appear on the opposite side of the screen. The participants viewed the scene and made a judgment about whether the scene is odd via button press. Whether the "odd" response button was on the left or right side of the button box was counterbalanced across participants (see *Figure 4*). Scenes were also counterbalanced for whether they appeared on the left or right side of the screen. In addition, the picture type was counterbalanced across participants, such that each participant saw each scene once, but each scene was shown in each condition across participants. Finally, participants completed a demographics questionnaire. The experiment lasted approximately 45 minutes.

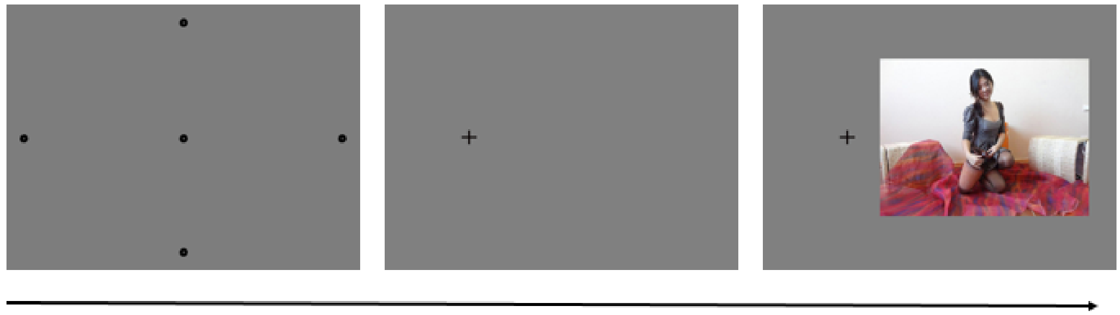

Figure 4. In each trial, participants first saw a five-point calibration followed by a fixation cross to one side (left, in this example). Once the participant was focused on the fixation cross, the picture would appeared on the opposite side (right, in this example).

Data Analysis

For the analysis, we were interested in examining whether there was an interaction between picture type and experimental groups on our behavioural measures and eye movement measures. We were additionally interested in examining whether experimental groups differed in performance and processing during the oddity tasks, as well as whether there were general differences in processing between social and visual oddity scenes.

Behavioural measures

We calculated accuracy and response time for each trial as our behavioural dependent variables. Accuracy was defined as whether individuals responded with the correct oddity type – whether the scene was odd or normal. Response time was calculated from the onset of the scene until a response was made.

Eye movement measures

A region of interest (ROI) was defined as 1° of visual angle around the edges of the odd element of each scene. The buffer allowed for variance due to eye tracker and participant error in determining eye position. Normal scenes were excluded from analysis as we were interested only in differences in how individuals differ in cognitive processing of odd stimuli. This mirrors the analysis completed in Benson et al. (2016). We were theoretically motivated to examine how participants were processing the targets present within the ROI. Thus, only trials where participants fixated within the ROI to make their oddity judgments were analyzed.

Early processing measures. We examined *first fixation duration* (duration of the first fixation within the ROI), the *first gaze duration* (duration of all fixations before the eyes move elsewhere in the scene), and the *latency to target region* (time from scene onset to the initial fixation on the ROI), which reflected how well the oddity was first noticed when the scene was first presented. These variables allowed us to investigate the cognitive processes that guide the initial detection and processing of oddities.

Late processing measures. We also analyzed three late processing measures, which included the *mean number of visits to the target region* (the number of times that the eyes enter the ROI), *mean number of fixations* (the total number of fixations made within the ROI), and *mean total time* (sum of all fixations within the ROI). These variables allowed us to examine the processing that occurs after the oddity has been fixated on.

Multilevel models

In the current study, we were interested in examining whether there was an interaction between experimental group and picture type. We were additionally interested in whether there were differences in performance and processing between high and low AQ, and whether there were any general differences in processing between social and visually odd conditions.

Interaction between experimental group and picture type. Eight multilevel models were run to examine each of the behavioural and eye movement measures. To examine the interaction between both predictors, we effects coded experimental group (high AQ group =1; low AQ group = -1) and picture type (social oddities = 1; visual oddities = -1). Each model had two levels, where trials were nested within participants to account for within participant differences in the number of trials. The data were analyzed using the nlme package (Pinheiro, Bates, DebRoy & Sarker, 2014) in R. We used a random intercept, fixed slope model for both behavioural and eye movement variables because we did not expect any variation in trial performance within participant:

$$y(dependent\ variable)_{ij} = \beta_0 + \beta_1(experimental\ group)_j + \beta_2(picture\ type)_{ij} + \beta_3\left(experimental\ group_j * picture\ type_{\ ij}\right) + u_{0j} + e_{0j}$$

Main effects of experimental group and picture type. To examine the main effect of experimental group and picture type respectively, another eight multilevel models were used to examine each of the behavioural and eye movement measures. Experimental group (high AQ group = 1; low AQ group = -1) and picture type (social oddities = 1; low AQ group = -1) were effects coded. Again, each model had two levels, where trials were nested within participants. We used a random intercept, fixed slope model for both behavioural and eye movement variables because we did not expect any variation in trial performance within participant:

$$y(dependent\ variable)_{ij} = \beta_0 + \beta_1(experimental\ group)_j + \beta_2(picture\ type)_{ij} + u_{0j} + e_{0j}$$

For both sets of models, the intraclass correlation for response time was .51 (i.e., greater than .10), indicating that the multi-level model would be helpful to account for within participant differences

Results

Examining the effect of ASD-like traits

To examine any underlying cognitive differences across the ASD continuum, we examined whether there was an interaction between the AQ group and picture type (whether there were group differences depending on the complexity of task). See Table 2 for the summary statistics of the dependent variables.

Interactions between AQ group and picture type. There were no significant interactions between picture type and experimental group, all *p*s > .08 (see Table 3).

Table 2

Summary statistics for behavioural and eye movement variables

	All		High AQ		Low AQ	
	M	*SD*	*M*	*SD*	*M*	*SD*
Behavioural						
Accuracy (%)	79	12	76	12	81	12
Response Time (ms)	2286.44	1083.09	2327.09	1103.32	2254.30	1078.83
Initial Processing						
First Fixation Duration (ms)	218.60	31.76	220.03	30.55	217.48	32.99
First Gaze Duration (ms)	344.15	83.43	333.85	69.77	352.29	92.83
Elapsed Time to Target (ms)	656.99	315.99	701.34	254.66	621.92	356.20
Late Processing						
Number of Entries	0.75	0.28	0.75	0.29	0.74	0.28
Fixation Count in Target	5.68	2.05	5.69	2.03	5.66	2.09
Total Time in Target (ms)	1347.24	609.45	1357.59	594.73	1339.06	627.73

Table 3

Results for the effect of interaction between picture type and experimental group

Dependent Variable	*B*	*SE*	*DF*	*t*	*p*
Behavioural					
Accuracy	-.01	.01	3617	-1.24	.22
Response Time	34.52	19.67	3617	1.76	.08
Initial processing					
First Fixation Duration	1.92	2.17	1762	.88	.38
First Gaze Duration	6.95	6.22	1762	.88	.38
Elapsed Time to Target	30.59	20.31	1762	1.51	.13
Late Processing					
Number of Entries	.00	.01	3617	.28	.78
Fixation Count in Target	.01	.04	1762	.28	.78
Total Time in Target	.20	11.31	1762	.02	.99

Experimental group (high vs. low AQ). If traits found in ASD when compared to TD individuals indeed generalize to individuals within the general population based on their level of ASD-like traits, we hypothesized that there would be behavioural differences between high and low AQ groups. Alternatively, because high and low AQ groups are both part of the general population, they may not display any overt behavioural differences; any differences may only emerge when looking at underlying cognitive processes. Here, we found that the high AQ group was not significantly different from the low AQ group in response time (b = 10.00, SE = 273.89, t (75) = -.04, p = .97) and accuracy (b = .01, SE = .02, t(75) = -.72, p = .48). Overall, high and low AQ groups did not significantly differ on initial or late processing eye tracking measures, all *p*s > .34 (see Table 4). A positive *b* value indicates that the high AQ group had higher values for that specific dependent variable, whereas a negative *b* value indicates that the low AQ group had higher values for that specific dependent variable.

Table 4

Results for the effect of experimental group (high AQ vs. low AQ groups, controlling for picture type)

Dependent Variable	*B*	*SE*	*DF*	*t*	*P*
Behavioural					
Accuracy	.012	.017	75	-.72	.48
Response Time	10.00	273.89	75	-.04	.97
Initial processing					
First Fixation Duration	-2.52	6.14	75	-.41	.68
First Gaze Duration	14.53	15.01	75	.97	.34
Elapsed Time to Target	-26.84	79.69	75	-.34	.74
Late Processing					
Number of Entries	.012	.05	75	-.23	.82
Fixation Count in Target	.078	.15	75	.52	.60
Total Time in Target	26.22	50.06	75	.52	.60

Picture type (socially vs. visually odd pictures). Participants were significantly but only slightly more accurate in identifying socially odd pictures than visually odd pictures, *b* = .01, *SE* = .01, *t*(3618) = 2.14, *p* = .03. Differences in processing socially odd and visually odd pictures were reflected in early and late processing eye movement measures as well. Participants spend more time initially processing the visually odd ROI than socially odd ROI, reflected in first fixation duration (*b* = -10.04, *SE* = 2.16, *t*(1763) = -4.65, *p* < .01) and first gaze duration (*b* = -49.69, *SE* = 6.17, *t*(1763) = -8.05, *p* < .01). A longer initial processing time, reflected in first fixation and first gaze durations, typically indicates that participants are processing visual oddities more than social oddities. For late processing eye movement measures, we found that participants re-entered the ROI more often for visual than social oddities (*b* = -.20, *SE* = .01, *t*(3618) = -13.40,

$p < .01$), had more fixations within the ROI for visual than social oddities ($b = -.31$, $SE = 0.04$, $t(1762) = -7.71$, $p < .01$) and spent more time in visual than social oddities ($b = -93.88$, $SE = 11.23$, $t(1763) = -8.36$, $p < .01$). These measures form a similar pattern where participants re-inspected and fixated longer and more often on visual oddities than social oddities, likely due to reinterpretation and regrouping necessary (e.g., girl with a third leg) of the visual features in the visual oddity condition.

There is one caveat in interpreting the differences in processing of visual and social oddities. For this set of analyses, we focused on target processing measures. However, we found that overall participants were more likely to directly fixate visual oddity ROIs (60.17% of trials) than social oddity ROIs (39.45% of trials), $t(152) = -4.61$, $p < .01$. Thus, because eye movement measures were calculated based on patterns when fixated, there were far fewer data points in the socially odd condition. Interestingly, accuracy remained high (78.65%) even when participants did not directly fixate the ROI, indicating that participants were able to detect oddities with peripheral information. Critically, high AQ individuals did not differ significantly from low AQ individuals in the number of trials where they fixated within the ROI for visual oddities ($t(75) = .61$, $p = .54$) or for social oddities ($t(75) = .32$, $p = .75$).

Post-hoc analysis: examining saccade length into region

If participants were identifying scene oddity without needing to directly fixate within the region, we explored whether there was a difference in peripheral information processing between visual and social oddities. Past research suggests that spatial attentional networks are different for ASD individuals, where less attention is deployed for peripheral information (Frey et al., 2013; Townsend et al., 2001). As a post-hoc analysis, we examined participants' saccade length into region, which reflects the extent of peripheral information processing by examining the length of the saccade participants made prior to looking at the oddity (Rayner, 1978). A longer saccade length indicates that more information is processed in the periphery because participants were able to deduce the oddity from farther away. This indicates more ease of processing. To analyze the data, we again used a 2-level multilevel model to estimate the random intercept of saccade length into region where trials were nested within participants. Predictor variables include experimental group and picture type:

$$y(dependent\ variable)_{ij} = \beta_0 + \beta_1(experimental\ group)_j + \beta_2(picture\ type)_{ij} + \beta_3\left(experimental\ group_j * picture\ type_{ij}\right) + u_{0j} + e_{0j}$$

We found a significant interaction between AQ group and picture type, *b* = -8.31, *SE* = 3.00 , *DF* = 1624, *t* = -2.77, *p* < .01 (see Table 5). To follow up this interaction, we examined the simple slopes at high and low AQ groups respectively (see Table 5). We found that for the low AQ group, individuals had a longer saccade length into region for social than visual oddities, *b* = 8.19, *SE*= 4.03, *DF*= 1624, *t* = 2.03, *p* = .04. If this pattern persists at full power, this would suggest that individuals with low levels of ASD-like traits processed more peripheral information for social than visual oddities. For the high AQ group, however, the difference in saccade length into region between visual and social odd scenes was not significant *b* = -8.44, *SE* = 4.45, *DF* = 1624, *t* = -1.90, *p* = .06. If a similar pattern is found at full sample size, this result would suggest that those with more ASD-like traits do not differentially process the peripheral information in visually and socially odd scenes.

Table 5

Post-hoc analysis: results of the effect of interaction between picture type and experimental group

Predictor Variable	*B*	*SE*	*DF*	*t*	*p*
Saccade Length into Region					
AQ group	-.91	3.76	75	-.24	.81
Picture type	-.13	3.00	1624	-.04	.97
Interaction: AQ group x picture type	-8.31	3.00	1624	-2.77	.01*
Follow up: High AQ					
Picture type	-8.44	4.45	1624	-1.90	.06
Follow up: Low AQ					
Picture type	8.19	4.04	1624	2.03	.04*

* significance at $p < .05$

Chapter 3

Discussion

In the current study, we were interested in examining ASD as a full spectrum that extended into the general population – whether individuals with high or low levels of ASD-like traits would differ in cognitive processing of social scenes. Moreover, we were interested in examining whether the pattern of impairments found in individuals diagnosed with ASD when processing complex but not simple information was reflected similarly in subclinical populations (Minshew & Goldstein, 1998). Specifically, we hypothesized that individuals with high ASD-like traits would be impaired on the more complex social oddity task but not at the simpler visual oddity task – reflected in both response time and eye movement measures.

Contrary to our hypotheses, we found no differences between individuals with high and low AQ scores in the context of low power. Individuals with high AQ did not differ on accuracy or response time than individuals with low AQ. When focusing on eye movement analyses, we additionally did not replicate Benson et al. study's (2016) pattern of results when comparing high and low AQ on early and late eye movement measures. These results reflect that regardless of the level of self-reported subclinical traits, individuals were not significantly different in how accurate or quick they are in their interpretation and processing of social contexts. The current results contrast the past literature that support a dimensional conceptualization of ASD, where subclinical individuals with high AQ relative to low AQ showed a similar cognitive processing style as did individuals with ASD relative to TD (Baron-Cohen et al., 2001; Bayliss & Tipper, 2006; Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010).

As expected, we additionally found differences in how individuals processed social and visual oddities. A similar pattern of results emerged across both behavioural and eye movement variables. Behaviourally, individuals were more accurate in identifying socially than visually odd pictures, but at a small effect size. At first glance, participants spent more time processing social oddities than visual oddities. Overall, individuals revisited the visual oddity more often, resulting in a higher number of fixations and longer mean total time than social oddities. This overall pattern of results replicates past findings comparing ASD and TD individuals (Benson et al., 2016). Visual oddities consist of physical violations (e.g., girl with third leg) that were more perceptually unusual than social oddities whereas social oddities are improbable but exist more readily in the real world than visual oddities (De Graef, 1998). Overall, we replicated past findings that participants process visually and socially odd scenes differently.

However, another caveat to consider when interpreting the results is there are twice as many data points for visual than social and visual conditions. Participants fixated within the visually odd region twice as often as the socially odd region. In the ROI analyses (e.g., first fixation duration within the region), trials where the participant did not look within the odd region were discarded, resulting in twice as many trials for visually odd than socially odd scenes. Despite the difference in eye fixations between visually and socially odd scenes, accuracy remained high for both scene types (79% while chance is 50%). This suggests that different cognitive processes are being engaged to identify oddity for visually and socially odd scenes. For visual scenes, participants need to look at the oddity directly to process the oddity; for social scenes, participants may be relying on peripheral information to accurately respond. Although there was a difference between visual and social scene types, this difference may simply reflect different underlying processes for the identification of oddities.

3.1 Exploring peripheral social cues

If individuals do not need to directly fixate in the odd region to identify whether the scene is odd, there may be differences in the amount of peripheral information that individuals process for socially and visually odd scenes. Past research suggests that ASD and TD individuals differ in how spatial attention is allocated; ASD individuals allocate less attention to peripheral information (Frey et al., 2013; Townsend et al., 2001). To explore this hypothesis, we examined the saccade length into region, which is the saccade distance required prior to locating the odd region. We found an interaction between AQ group and picture type, where individuals with low AQ had a longer saccade length into region for social than visual oddities, but no such difference was found in individuals with high AQ. One possible way to account for this result is that low AQ individuals may use different strategies to determine the oddity of each scene type. For instance, in both groups visual oddities encourage a strategy of examining visual information closer to the point of fixation, resulting in the shorter saccade lengths. However, the strategy diverges between groups for social scenes. For instance , the longer saccade lengths could suggest that low AQ individuals are integrating prior knowledge of social norms to guide their search. In contrast, there is no evidence to suggest that high AQ individuals are processing the two types of scenes differently. Thus, these results suggest that there may be processing differences between groups, but a higher-powered study would be needed to support these effects.

Some of the additional peripheral information that low AQ individuals may be processing could be socially relevant cues, such as another's gaze. Joint attention is when an individual directs their own attention towards an object that another is attending. Joint attention is one of the key examples of social impairment found in ASD individuals, found to persist across the lifespan (Dawson et al., 2004; Morgan, Maybery & Durkin, 2003; Redcay et al., 2012). One key component to exhibiting joint attention is the perceptual ability to identify another's gaze and use this information, which is also impaired in ASD relative to TD individuals (Fletcher-Watson, Leekam, Benson, Frank & Findlay, 2009; Leekam, Baron-Cohen, Perrett, Milders & Brown, 1997) as well as high relative to low AQ individuals (Bayliss & Tipper, 2006). Our current set of stimuli includes at least one person in each scene, so that all stimuli have social information, varying only in the level of complexity of processing required (i.e., simple processing for visual oddities or complex processing for social oddities). Only a few stimuli show a direct fixation on the oddity, with a few more examples found in the social than visual oddity condition (see

Supplementary Information in Benson et al., 2015 for the full set of stimuli). Nevertheless, participants who exhibit a typical gaze following response would be directed closer towards the oddity than another who scans the scene randomly. Thus, low AQ individuals may be detecting socially directed gaze as part of the additional peripheral information processed in socially odd scenes. Future studies could investigate differences in processing visual and social oddities by directly manipulating gaze direction to orient towards or away from oddities or other search targets.

Since only a small portion of our stimuli had people correctly orienting gaze direction towards the target, numerous other social cues could be contributing to the additional peripheral information processing found in low AQ individuals. For example, there were differences in how ASD and TD individuals orient their attention towards humans in general (Fletcher et al., 2009). Within a scene, ASD individuals may not show preference for processing humans within the scene until later in a trial whereas TD individuals show this preference for prioritizing their attention towards humans within the scene at first fixation (Fletcher et al., 2009). In our study, high and low AQ individuals may be fixating on different components of the scene (e.g., objects or people) at first glance. If patterns found when comparing ASD and TD individuals are found in high relative to low AQ individuals, where high AQ individuals do not prioritize their attention towards humans until later in processing than low AQ individuals, then this could influence how much social information high AQ individuals can use to guide scene processing. Thus, low AQ individuals who attend to social cues provided by humans early on can benefit from additional social information to guide their search for the oddity within the scene. Low AQ individuals may be attuned to this action related information shown by individuals surrounding the oddity. Of our stimuli, a small number of scenes include examples where someone is directly interacting with the oddity (see Supplementary Information in Benson et al., 2015 for the full set of stimuli). For example, in the stimuli where a baby is being thrown, the individual exhibiting the throwing motion and the individual exhibiting the catching motion can both be used as a cue to guide someone's gaze towards the oddity. Our analysis focused on eye movement patterns regarding only the immediate oddity (e.g., ROI defined around the baby) without encompassing other social cues. Overall, the real-world scenes used in this study had a variety of possible social cues that can be used to quickly identify the oddity of social scenes; future studies could control for these social cues to investigate how they guide scene processing of social contexts.

3.2 ASD: Categorical or dimensional?

In our planned comparisons, we found no significant differences in cognitive processing between individuals with high and low AQ scores. If this null finding persists at full power, it would contrast past results that have found differences in cognitive processing within the general population. This would still be consistent with the categorical conceptualization of ASD; while cognitive processes in the general population can be variable, they are qualitatively distinct from individuals diagnosed with ASD, who have experienced enough impairment in daily functioning to warrant a diagnosis. However, the results of this study would be inconsistent with the growing body of literature that suggest that ASD traits vary along a continuum with no identifiable bimodal distribution in cognitive traits that distinguish clinical from non-clinical individuals. Regardless, there remains the issue of heterogeneity in ASD, where there is high variability within the diagnostic category which highly overlaps with other disorders such as social pragmatic communication disorder. Rather than using a dimensional approach, future investigation of ASD may want to focus on examining subcategories based on the main three areas of impairment in ASD: social deficits, communication difficulties, and rigid or repetitive behaviours (Grzadzinski, Huerta & Lord, 2013; Jiao et al., 2011). Happé et al. (2006) argue that rather than focusing on a single genetic or cognitive cause for ASD that these three domains of impairment may map on to distinct causes; together, different combinations of impairment in these domains can lead to the high variability in symptom constellations found for individuals with ASD.

Another way of conceptualizing ASD as a dimension is by looking at the dimensional variation of the three core features that make up ASD – maybe this would offer a more precise correlation between certain cognitive processes with specific features of ASD. In our study, we examined variation in total AQ scores, which is an aggregate score of three distinct factors or subscales: social interaction, attention to detail and poor communication skills (Austin, 2005; Hoekstra et al., 2008; Hurst et al., 2007). Rather than approaching the continuum as the degree to which an individual has *any* type of ASD-like traits, we may want to focus on specific constructs that make up the core symptoms of ASD (Happé et al., 2006). In our sample, there may be variability in which subscales contribute to high or low AQ scores. For example, individuals in our sample may have a high AQ score because they endorsed roughly the same number of ASD-like traits across social interaction, attention to detail and poor communication skills subscales. Alternatively, they may have endorsed a high number of ASD-like traits on only one subscale (e.g., social interaction). Future studies could focus on relating specific constructs, as measured by subscales, with specific cognitive or social impairments.

Certain subscales might be closely related with some underlying cognitive patterns found when comparing ASD and TD individuals. For example, an individual with more locally focused attention, scoring more ASD-like on the attention to detail subscale, may exhibit more ASD-like perceptual processing as evidenced by eye movement record (e.g., repetitive re-entries found in ASD individuals in Benson et al., 2016). Stevenson et al. (2016) have found that the attention to detail subscale of the AQ was correlated with differences in perceptual processing of Navon figures, where higher AQ scores was correlated with more featural processing. Similarly, an individual's score on the social interaction subscale may be more highly correlated with the ability to pick up peripheral social cues such as eye gaze. Rather than focusing on a single genetic or cognitive cause for ASD, the three core features of ASD may map on to distinct causes and underlying cognitive processing; together, different combinations of impairment in these domains can lead to the high variability in symptom constellations found in individuals with ASD. In the current study, we selected individuals from the high and low ends of the AQ spectrum and thus would not get natural variation when looking at subscales. Thus, one future direction may to examine how the attention to subscale may correlate with eye movement patterns or how the social interaction subscale may correlate with the ability to quickly process social cues like eye gaze.

3.3 Limitations

In our study, we found significant differences between high and low AQ individuals on levels of Big Five traits and depressive symptoms that could be interpreted as potential confounds, should significant differences in cognitive processing emerge at full power. However, these group differences in Big Five traits replicated past research suggesting that high AQ individuals score higher on neuroticism and lower on extraversion and agreeableness (Austin, 2005). There is also considerable comorbidity between ASD and depression (Sterling, Dawson, Estes and Greenson, 2007). Moreover, individuals within the Broader Autism Phenotype have rated higher levels of social loneliness (Jobe & White, 2007) and found to have higher risk of social phobia or mood disorders (Piven & Palmer, 1999). This may reflect similar etiology between ASD and other mental disorders (Cath, Ran, Smit, van Balkom & Comijs, 2007). Thus, it is important to consider how ASD or ASD-like traits relate to other disorders as well, and whether the presence of other disorders is a confounding factor to understanding ASD or reflective of common etiology.

We chose to examine the extremities of the ASD continuum within the general population, where differences in underlying cognitive processing should be most evident; the results from our study may not necessarily generalize when interpolated or extrapolated. This design of splitting the sample into a high or low AQ group based on extreme scores is consistent with some of the previous literature in this area (Grinter et al., 2009; Sutherland & Crewther, 2010); others have opted to analyze as a continuous variable (Bayliss & Tipper, 2006). However, there are two main limitations to consider when interpreting results based on this approach. Firstly, there has not been a consistent way of defining adequate cut-offs for these high and low groups, with variation in threshold of AQ cut-off scores (Grinter et al., 2009; Ruzich et al., 2015; Sutherland & Crewther, 2010). We calculated our appropriate cut-off scores from a selected percentile threshold and a large sample of completed AQ questionnaires (n = 3170) to address this. Second, this approach removes any variance in ASD-like behaviour that may exist within these high and low AQ groups. This is important to consider as the AQ distribution has a positive skew, such that the bottom *n*th percentile of individuals is qualitatively more similar to each other than the top *n*th percentile (Ruzich et al., 2015). Future research on ASD-like traits can supplement the current work by examining more nuanced differences or correlations of the full spectrum, including individuals in the middle of the spectrum.

Finally, some caution must be taken when interpreting the results of this study as it was underpowered. The planned sample size (n = 168) was not reached; a total of 77 participants were collected. At an assumed small to medium effect size (d = .3 to .5) only 47% - 87% power was reached. The effect sizes were estimated based on a) prior research that has found milder but qualitatively similar traits for ASD individuals within the Broader Autism Phenotype (Le Couteur et al., 1996; Piven et al., 1997), and b) the effect size (d = .65) of a study with similar experimental design comparing clinical and non-clinical groups (Benson et al., 2016). Although there has been prior literature examining the cognitive underpinnings of the ASD in the general population (Bayliss & Tipper, 2006; Grinter et al., 2009; Sutherland & Crewther, 2010), effect sizes have not been reported. Currently, an accurate quantitative estimate of how much milder an effect should be expected in the general population and hence the ideal sample size has not been examined. Thus, the null difference between high and low AQ groups in this study should be interpreted in the context that depending on the actual effect sizes, we cannot be certain whether we have reached relatively acceptable power (i.e., estimate of 87% power, if d = .5) or whether we are currently underpowered (i.e., estimate of 47% power, if d = .3).

3.3 Conclusions

The key question of this study was whether ASD can be conceptualized dimensionally and whether theories of ASD can extend to the general population, especially because all these non-clinical individuals have not met criteria to satisfy a diagnosis of ASD. Our planned analyses show no significant AQ group differences in processing, suggesting that despite the variation in ASD-like traits, cognitive processing is note different amongst all non-clinical individuals, with no systematic variation associated with ASD-like traits. However, at the most conservative estimate, this study is underpowered and thus it is inconclusive whether we may find any of our hypothesized AQ group differences at full power. Through our exploratory analysis, we found that low AQ individuals differ in the amount of peripheral information they process for visually and socially odd scenes that is absent in high AQ individuals – possibly due to differences in processing of peripheral social cues. If replicated at full power, this pattern would suggest that there are key differences in how individuals who have low and high ASD-like traits use social cues to aid scene processing. This use of social cues in scene processing in low AQ individuals that is absent in high AQ individuals support the dimensional view of ASD, allowing us to examine perceptual processes that are found for individuals with the diagnosis but in individuals without the functional impairment associated with ASD. Future studies could supplement current work by focusing on a more nuanced conceptualization of ASD by examining dimensional variation or subcategories based on each of the three key domains of impairment in ASD.

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