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Autistic Traits and Cognitive Biases for Emotional Faces in Neurotypicals

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Abstract

Cognitive biases can involve the tendency to extract some sensory inputs while ignoring others. Cognitive biases impact perception, and subsequent processing decisions made on the basis of perception. Cognitive biases can disrupt accurate and efficient processing of social information, and may underlie core features of social communication difficulties. How cognitive biases contribute to atypical social processing associated with autism spectrum disorder (ASD) traits is unknown. We examined whether cognitive biases for emotional faces were related to scores from the Autism-Spectrum Quotient (AQ), and whether our measures of cognitive biases from a dot-probe paradigm with concurrent eye tracking were comparable. We did not find sufficient evidence to relate ASD traits and cognitive biases. We found limited eye movements made during the paradigm and no relationship between the two concurrent measures. We highlight outstanding questions in the investigation of ASD traits and cognitive biases through the dot-probe paradigm and eye tracking.

Keywords

Autism Spectrum Disorder, Autistic Traits, Cognitive Bias, Perception, Emotion Processing, Dot-Probe Paradigm, Eye Tracking

Summary for Lay Audience

Cognitive biases describe patterns of thinking that affect the decisions people make. We take shortcuts to think quickly about complex problems, and cognitive biases help us to do this. Most biases are stable tendencies that people will continue to display over time, and can affect how we pay attention to, remember, and interpret information. Cognitive biases can look like social and behavioral problems when people deal with information differently, and they may be linked to some of the social and behavioral problems often reported in autism. If there is a link between these two kinds of problems, people with more autism-like features would look at others' faces differently than people without social and behavioral problems. We largely found people with more autism-like features did not show different cognitive biases when looking at others' faces, but that factors of our design might have contributed to this being the case. We discuss ways to adapt the current design for future use.

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ADHD	Attention-deficit/hyperactivity disorder
ASD	Autism spectrum disorder
AQ	Autism-Spectrum Quotient
MDD	Major depressive disorder
OCD	Obsessive compulsive disorder
PTSD	Post-traumatic stress disorder
RDoC	Research Domain Criteria
α	Alpha
p	Probability value
ρ	Spearman's rho correlation coefficient
cm	Centimetre(s)
ms	Millisecond(s)
RT	Reaction time
RTn	Reaction time without eye movements
EM	Eye movements
Hz	Hertz
N	Number of participants
S.D.	Standard deviation
M	Mean
Mdn	Median
F	F distribution value
D	Kolmogorov-Smirnov test statistic
Q	Benjamini-Hochberg false discovery rate
R	Pearson's correlation coefficient
AOI	Area of interest
SOA	Stimulus onset asynchrony
±	Plus or minus

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Chapter 1

1 Introduction

Cognitive biases refer to systematic patterns in which perception and experience inform how we navigate the world. Often considered deviations from optimal or rational responses (Haselton, Nettle, & Murray, 2015), cognitive biases are thought to arise as a consequence of the inherent limitations to cognitive processing. Although they can develop to improve efficiency in information processing, cognitive biases may also carry consequences for accuracy in information processing. Most commonly conceptualized as the tendency to preferentially process some sensory inputs while ignoring others, cognitive biases are well documented across many aspects of human cognition. Biased processing patterns are indeed documented for decision-making and memory skills (Teovanovic, Knezevic, & Stankov, 2015), alongside attention, interpretation, and reasoning domains (Mathews & MacLeod, 2015). Given the impact of biased processing to daily functioning, it follows that alongside the profound perceptual differences they can bring, cognitive biases may also contribute to detriments in social communication and emotion processing abilities.

The processes which integrate to give rise to cognitive biases are not fully understood, and this holds true across the variety cognitive domains in which they have been measured. However, there is some evidence to suggest cognitive biases are at least in part self-reinforcing, such that biased processing leads to cyclical and preferential processing tendencies (Wachtel, 1994). Within this cycle, an individual who preferentially processes certain inputs over others is more likely to repeat the same pattern and ignore other inputs over time. Cognitive biases may indeed become rigid and difficult to shift over time, even if they arise from irrational or competing processes. Rigidity in taking in information over time can serve to inhibit how information is processed; the individual will overlook key information, simply because it falls outside of the scope of the processing pattern. Cognitive biases may therefore lead to atypical or inhibited patterns of social and cognitive processing.

Further investigation of the factors underlying the development and maintenance of cognitive biases may shed light on how these patterns are impacted, especially as they relate to atypical and systematic differences in social and emotional processing. In the current study, we will explore multiple sources of evidence for insight into how the existing models of cognitive biases may inform which procedures should be used to measure cognitive biases. In doing so, we will address how cognitive biases might relate to broad social, emotional, and behavioral characteristics which have been associated with atypical perceptual outcomes.

The social world is a complex, dynamic environment which offers continuous and often unpredictable sensory information. To make sense of this information, automatic processes underlying our sensory systems are regularly engaged to counterbalance some of the limitations to conscious processing. Often measured using priming techniques, whereby the presentation of a stimulus biases further processing of related stimuli, automatic processes such as unconscious attention can arise to improve processing speed, for example (Wheatley & Wegner, 2001). Complex sensory inputs which carry dynamic social meaning can thus engage automatic processes, such that cognitive resources are conserved to manage other complex sources of input without conscious input. Cognitive biases fall into line with these more automatic processes, which can develop to deal with highly familiar and easily recognized inputs (National Research Council, 2015). Our sensory systems come to rely on automatic processes, including cognitive biases, to efficiently adapt and respond to changes in the environment.

Efficiency in information processing can allow an individual to be more successful in a given social environment (Grill-Spector, Weiner, Kay, & Gomez, 2017), which in turn generates a cyclically impactful increase in adaptive social behavior (Haselton, Nettle, & Murray, 2015). Previous evidence shows that perceptions and the subsequent decisions made on basis of those perceptions can occur more quickly if there are automatic processes already in place, regardless of whether those processes adhere to typical and rational functioning (Gigerenzer & Goldstein, 1996). As a result, automatic processes allow meaningful conclusions to be drawn in response to inputs and experiences which can occur even outside of the bounds of conscious attention. The more automatic aspects of processing are not fully understood, but they are hypothesized to arise due to influence from separate neural networks (Badgaiyan, 2012).

The emotional behavior of others is a substantive contributor to the complexity of information available from the social environment. Including facial expressions and gestures, emotional behavior is used to convey information about the internal states and intentions of others. A vital aspect of social functioning therefore relies on the efficient and accurate perception of dynamic emotional inputs. As our sensory systems develop from infancy through adulthood, cumulative experience with perceiving and responding to emotional faces can have further impacts to face processing later in development. The adaptive and automatic application of previous experiences allows meaningful information to be attributed to a given input (Scott & Monesson, 2009). The more automatic processes involved in social communication and emotion processing are inherently more subject to bias, due to the judgment-based categorization of inputs which occur rapidly to deal with incoming information.

1.1 Cognitive Biases and Social Perception

The perception of information indeed defines how it may be judged; however, perception also defines how we decide to interact with others. In the absence of a typical stream of social inputs, such as in circumstances of social isolation, even aspects of perception which are not typically entirely reliant on social input can be negatively impacted. Social isolation has been attributed to reduced cognitive performance overall, in addition to disruptions in executive functioning (Cacioppo & Hawkley, 2009). Three domains of social ability which are fundamental to survival are impacted in particular (Brownlee, 2013), which result in cognitive, emotional, and behavioral difficulties due social isolation (Haney, 2018). The perception of social input is vital to how individuals will use adaptive strategies to navigate the social world, and whether maladaptive and atypical biases emerge in processing strategies. There are several accepted models currently in place to explain the outstanding question of how cognitive biases develop and are maintained. We will first consider the adaptive mechanisms which can give rise to cognitive biases, followed by the maladaptive and potentially deregulatory processes which can arise in social and perceptual domains.

1.1.1 Adaptive Mechanisms

Cognitive theories which explain the mechanisms underlying cognitive biases are generally predicated on the assumption that adaptive responses can facilitate efficient and accurate processing. These adaptive processes are formed from the substrate of perception and perceptual judgments (Tucker & Luu, 2007)**,** and in turn function to derive meaning from complex inputs. Cognitive biases may therefore also function to prime our sensory systems to capture information that is highly relevant, or can be quickly processed due to its familiarity. The automaticity of cognitive biases, however, can disrupt some of the typical processing strategies most people use. For example, if there are underlying disruptions to typical and rational functioning, the adaptive response underlying biased processing of relevant information instead drives a maladaptive or irrational focus on negative information, such as the cognitive biases seen in major depressive disorders (MDD). Deregulation in the ability to access and to form novel positive perceptual judgments may lead to severe impacts to social outcomes, and further drive negative biases over time.

Indeed, the automatic processes underlying cognitive biases can function to develop and maintain certain atypical behavioral tendencies and preoccupations. As another example beyond MDD, the fear of social failure is a common preoccupation for many individuals with social anxiety disorders. Negative cognitive biases for social information are often observed, where negative social outcomes are expected to a higher degree of probability compared to judgments by neurotypical peers (Bar-Haim, Lamy, Pergamin, Bakermans-Kranengurg, & van Ijzendoorn, 2007; Constans, Penn, Ihen, & Hope, 1999). Cognitive models of anxiety disorders propose that the automatic and selective processing of threat-related, in this case anxiety-related and social information, contributes to the core features used to characterize anxiety (Liu, Li, Han, & Liu, 2017). In terms of daily functioning, an over-reliance on negative social information and ignorance of social inputs can limit the scope of an individual's social experience. Previous evidence has shown that individuals with social anxiety disorder rated negative social outcomes as being more probable and costly, compared to ratings by neurotypicals peers (Rheingold, Herbert, & Franklin, 2003). In another study of social anxiety, anxious individuals also showed an atypical presentation of cognitive biases for threatening social information (Asmundson & Stein, 1994), findings similar to which have been widely replicated (for a review, see Bar-Haim et al. 2007). Cognitive biases may indeed arise due to adaptive mechanisms, which can be deregulated to drive maladaptive responses. This interpretation would suggest that cognitive biases may play a substantive role in how individuals perceive and respond to the social world.

1.1.2 Evolutionary Mechanisms

The mechanisms underlying cognitive biases have also been suggested to arise due to biological predispositions, or from evolutionary mechanisms. Considering the evolutionary model, cognitive biases may explain why the adaptive and automatic aspects which are seen in typical, rational processing seem to become dysregulated. Survival, broadly termed, is predicated by the ability to identify and respond to danger. Survival is also supported by the automatic processes our sensory systems develop to resolve the complexity of inputs from the environment. Cognitive biases may thus contribute, due to the involvement of evolutionary mechanisms, to a priming of cognitive efficiency for certain types of information. Although a unified understanding of cognitive biases must acknowledge that they can occur due to processes which deviate from rationality, in essence as cognitive errors, this suggestion would imply an adaptive process is underlying cognitive biases as well. Through the evolutionary lens, cognitive biases are understood to promote survival in some cases, which are outlined below (Haselton, Nettle, & Murray, 2015). The departure from rational functioning which characterizes some cognitive biases is hypothesized to arise from evolutionary mechanisms which would otherwise improve information processing (Kahneman & Tversky, 1973). The evolutionary model describes cognitive biases as a consequence of once-adaptive mechanisms, even though the processes may not be adaptive in a given environment, for every individual, or at a certain time-point in our evolutionary progression.

1.2 Outcomes of Cognitive Biases

We further explore the previously outlined adaptive and maladaptive impacts of cognitive biases. Given the wide range of processes and outcomes associated with cognitive biases, we will focus on social and behavioral outcomes associated with cognitive biases and their impact to perception.

1.2.1 Biased Perception of Threat

We have previously outlined cognitive mechanisms which allow an individual to actively and even unconsciously respond to changes in a given environment. However, as described with respect to the evolutionary model of cognitive biases, processes which were once adaptive may be inappropriate to respond to a given environment or problem. One clear example of an adaptive cognitive biases, the auditory looming effect, describes a biased processing pattern whereby individuals preferentially process information that is judged to be closer in physical proximity compared to information outside of that judged proximity. For example, neurotypicals judged a sound with increasing intensity as being physically closer and more rapid in approach as compared to a sound with decreasing intensity (Neuhoff, 2001). The auditory looming effect has also been shown to be more pronounced for individuals who were in poorer physical condition by fitness and heart-rate outcomes compared to healthy controls; this association suggests a protective factor or mechanism may drive the individual to adapt to dynamic changes in the environment (Neuhoff, 2016). The perception of threat, and the automatic processes which develop to quickly perceive threatening information, may therefore drive cognitive biases for certain inputs compared to others (Haselton, Nettle, & Murray, 2015).

1.2.2 Biased Perception of Relevance

Automatic cognitive process similar to those underlying the perception of threat may also drive the perception of an input's relevance. For example, the biological relevance of a given stimulus plays an important role in the processing strategies that will be used, and this factor closely relates the modern social world to some evolutionary biases. From infancy, our sensory systems are predisposed to attend more to human compared to non-human faces (Farroni, et al., 2005; Johnson, Senju, & Tomalski, 2015). In adulthood, we are similarly primed to attend more to certain faces, and will show cognitive biases for infant faces compared to adult faces (Brosch, Sander, & Scherer, 2007). Interestingly, adults show more activity in reward-centered brain regions when viewing infant faces compared to adult faces (Kringelbach, et al., 2008), which might seem to suggest at the involvement of a reciprocal relationship which arose due to the biological relevance of the infants and the social relevance of the face more generally. Two different cognitive biases, in infancy and adulthood, therefore may work in symbiosis to support the survival and fitness of infants, who are often considered vulnerable and important members within the social world of adults. To the typical observer, human faces are not inherently threatening, therefore these biases are generally adaptive to social functioning and promote positive social interactions because they carry such high relevance for social functioning.

1.2.3 Biased Processing of Experience

Fitness and survival within a social environment depend on the ability and willingness to engage with others. Our sensory systems operate by bridging associations between inputs and expectations, and rely on knowledge bases built through experience. Commonly referred to as priors, these knowledge bases can be used to inform perception and subsequent perceptual decisions (Lee & Vanpaemel, 2018). Considering priors through the Bayesian account of cognitive biases, the adaptive processes we use to navigate the social world rely on previous experiences and judgments (Pellicano & Burr, 2012). Perceptual errors may occur in the absence of sufficient priors, however an over-reliance on priors may similarly lead to perceptual errors or atypical processing strategies. Cognitive biases are therefore impacted by the ability to perceive input, and can also contribute to how previous knowledge is used to inform the current processing strategy. Through the Bayesian account, cognitive biases may be attributed to an adaptive attempt to use previous experience, relying on priors to inform perception and the subsequent decisions made to adapt to a given environment.

1.2.4 Biased Processing of Rationality

As previously outlined, cognitive biases are perhaps most widely understood as processing errors, which deviate from rational functioning. In models of major clinical disorders, cognitive biases have been implicated in many of the behaviors and characteristics used to characterize symptoms. Despite the adaptive and protective factors which can give rise to cognitive biases, making consistent 'errors' in reasoning to preferentially capture some inputs while ignoring others can negatively impact how one perceives to the social world (Liss, Saulnier, Fein, & Kinsbourne, 2006). Interpreting cognitive biases through this mechanistic lens suggests that they may similarly drive tertiary traits and symptoms, which will be discussed in more detail below with respect to several clinical disorders.

1.3 Cognitive Biases in Major Clinical Disorders

In light of the well-established impact of information processing abilities on perceptual outcomes, researchers have become increasingly preoccupied with investigating the impact to social outcomes. Specifically, whether cognitive biases may be used to explain the development and maintenance of core features of major clinical disorders. For example, cognitive biases have been identified in clinical individuals as a bias for perceiving threatening, negative, and/or disorder-related information. As a result, the presence of cognitive biases has been implicated in maintaining the characteristics of anxiety disorders (Aday & Carlson, 2017; Bradley B. P., Mogg, Falla, & Hamilton, 1998; Dudeney, Sharpe, & Hunt, 2015; Eldar, et al., 2012; Hollocks, Ozivadjian, Mathews, Howlin, & Simonoff, 2013; Klein, et al., 2018; Lisk, Vaswani, Linetzky, Bar-Haim, & Lau, 2020). Similar implications have been made for addictive disorders (Wiers, Gladwin, Hofmann, Salemink, & Ridderinkof, 2013), post-traumatic stress disorder (PTSD; (Badura-Brack, et al., 2013), eating disorders (Mercado, Schmidt, O'Daly, Cambell, & Werthmann, 2020; Misener & Libben, 2020; Voon, 2015; Williamson, Muller, Reas, & Thaw, 1999), and MDD (Bergman, et al., 2020). Each of these disorders typically includes a characteristic reliance on negative and disorder-related information, driving further negative outcomes and experiences. Although the mechanisms which give rise to cognitive biases can be explained through processes which facilitate survival, disruptions to processing strategies are widely understood to occur alongside some of the core features of clinical disorders. The cyclical impact of cognitive biases is well-exemplified in models of anxiety disorders in particular, where individuals interpret social situations as being more negative compared to neurotypical peers, pay more attention to negative social information compared to positive, and continue to have difficulty with perceiving and interpreting positivity from social inputs (Beck & Clark, 1997).

1.3.1 Cognitive Biases in Neurodevelopmental Disorders

A key feature of many neurodevelopmental disorders is having difficulty shifting cognitive resources, such as attention, away from certain inputs and toward others. Similar to their proposed role in psychoaffective disorders such as anxiety, cognitive biases have also been proposed to explain some of the processing strategies used and social characteristics displayed by individuals with neurodevelopmental disorders. As an example, individuals with attention-deficit/hyperactivity disorder (ADHD) show cognitive biases for negative information (Melvyn, Chow, Vallabhajosyula, & Fung, 2020). Similar effects have also been reported to underlie problems with internalizing and externalizing which are commonly reported in association with other neurodevelopmental delays (Schmidt & Vereenooghe, 2020).

Other researchers, however, suggest that cognitive biases may arise due to artifacts from research methodology itself. In particular, that the inappropriate attribution of typical standards to populations for which they are not intended may lead to measurement artifacts (Haselton, Nettle, & Murray, 2015). Exploring this potential issue, researchers sought to identify whether cognitive biases were correlated with intelligence in a group of individuals with neurodevelopmental disorders. Indeed, deviations from rational thinking did correlate with intelligence, however only when a higher degree of cognitive ability or engagement was required to carry out the task (Stanovich & West, 2008). In light of the potential disparity between an individual's functional abilities demands of the typical or normative standards of measurement, whether cognitive biases are indeed artifacts of research methodology or arise due to underlying processing differences remains unclear.

As it stands, few studies incorporate appropriate methodology appropriate for assessing individuals with severe neurodevelopmental disorders, or choose to include neurodevelopmentally delayed individuals as participants. The resulting dearth of research into this important area was recently outlined in a review paper; a majority of the studies reviewed were found to have excluded individuals with neurodevelopmental disorders from participation (Schmidt & Vereenooghe, 2020), despite being in the position to benefit the most from more in-depth investigations into cognitive biases. Therefore, individuals with limited social, cognitive, and/or behavioral capacity can be systematically excluded from participation in the inquiries that should instead shed light on how biases in cognitive processing may impact multiple presentations of social functioning.

1.3.2 Cognitive Biases in Autism Spectrum Disorder (ASD)

We have discussed the impact of cognitive biases in explanatory models of a range of neurotypical and clinical samples. Most germane to the present study, however, are the impacts of cognitive biases to some of the core and often debilitating features of autism spectrum disorder (ASD). ASD is a neurodevelopmental disorder which impacts social communication and behavior, with diagnostic criteria for ASD currently including persistent impairments to social interaction and communication abilities, in addition to restricted and repetitive patterns of behavior, and unusual sensory interests (American Psychiatric Association, 2013). ASD symptoms and traits may have negative consequences on the ability to respond and relate to others; autistic individuals often struggle with emotion recognition and with interpreting the facial expressions of others, characteristic difficulties which have been linked with social communication skills more generally (Baron-Cohen, Golan, & Ashwin, 2009). Autistic individuals also show differences in social attention, however mixed evidence has yet to establish whether this could be due to a reduction in social orienting abilities (Dawson, et al., 2004; Guillon, Hadjikhani, Baduel, & Roge, 2014), or whether other mechanisms dictate social attention in association with ASD.

Cognitive biases for social information have been documented in ASD throughout various developmental stages. Taking the example of a free play scenario, autistic infants as young as 20 months have shown atypical social orientation, looking more frequently and for longer durations toward objects instead of people as compared to neurotypical peers (Swettenham, et al., 1998). This atypical social orientation was somewhat preserved, as by two years of age, autistic toddlers have shown difficulty following the gaze of others; interestingly, however, their ability to process directional information based on gaze was intact (Chawarska, Klin, & Volkmar, 2003). In older autistic toddlers, around 32 months, poorer face recognition abilities have been attributed to disruptions in attention, where autistic toddlers attended less to faces as compared to neurotypical controls (Chawarska, Volkmar, & Klin, 2010). Shifting throughout development, by 5 to 12 years of age, autistic children have shown intact social orientation and attentional mechanisms pertaining to social stimuli (Fischer, Koldewyn, Jiang, & Kanwisher, 2014). In adulthood, reduced social orientation and attention have been widely demonstrated (Moore, Heavey, & Reidy, 2012). Taken together, these mixed findings for cognitive biases and how they may shift across developmental stages highlight some of the challenges to the current investigations of processing biases more broadly, especially when comparing across studies. To offer a unified understanding of how cognitive biases are impacted and maintained in association with ASD appears to necessitate an approach from the perspective of multiple developmental stages, alongside multiple presentations of neurodevelopmental differences.

Despite the wealth of inconsistencies in the literature regarding cognitive biases and their specific impact to ASD, sensory perception and cognitive processing more generally are well known to be impacted in ASD. The mechanisms underlying this impact and the extent to which they dictate social and behavioral outcomes core to ASD remain unclear. A recent review described mixed evidence across a variety of paradigms as to whether significant differences could be found in cognitive biases between autistic individuals and neurotypical peers (Bergman, et al., 2020). Although the severity of ASD symptoms in these studies were largely found to be unrelated to cognitive biases across various paradigms, the review showed very few studies achieved adequate methodological quality. Due to methodological discrepancies with sample size, data reporting, and task demands, the researchers cited difficulty in reaching a unified understanding of whether cognitive biases differed across groups, and if so, what these differences may reveal about the underlying processes. Considering these issues in comparisons across and within paradigms, we agree it may be difficult to find a true effect if one does exist for cognitive biases, even if there are widely documented differences in perception more generally between autistic individuals and neurotypical peers.

Social information is indeed vital to adaptive functioning in the social world, however for autistic individuals and individuals with profound social and behavioral challenges, social experiences can be threatening, negative, or even aversive (Edmiston, Jones, & Corbett, 2016). One model which endeavors to explain processes underlying the social and cognitive differences in ASD is the eye avoidance hypothesis. The eye avoidance hypothesis describes the tendency for autistic individuals to systematically miss out on important social information when input from the eye region of a face (Tanaka & Sung, 2016). Attributed to the perceived level of threat in the eye region, information in this area can be systematically avoided, oriented away from, or ignored when autistic individuals view a face. Per this model, some of the profound face processing differences commonly reported in ASD may arise due to protective or adaptive factors. However, in combination with the other characteristic difficulties in ASD, the adaptive response may manifest as an atypical cognitive bias away from the eye region in order to avoid the threatening information (Jones, Carr, & Klin, 2008). Indeed often described as a social deficit in ASD, reduced attention and orientation toward the eye region may serve as a protective response to threat, however can also aggravate social deficits when other social inputs are systematically avoided from this important social area. To illustrate the dual role of cognitive biases in some of the adaptive and maladaptive features of ASD, we will describe additional processing strategies common to autistic individuals. These strategies include the enhanced drive to seek out explanatory information when faced with ambiguous circumstances, however only for circumstances related to physical, but not social stimuli (Rutherford & Subiaul, 2016). Autistic individuals also tend to process details within a scene more accurately compared to neurotypicals, however often have difficulty using contextual information to draw meaning about the overall scene whereas neurotypicals rely on context (Skewes, Jegindo, & Gebauer, 2015). Together, these differences in processing strategies might suggest at the impact that the interpretation of a given input impacts whether responses manifest with an adaptive, or maladaptive outcome.

An important limitation to a large portion of the current cognitive bias research is that studies rarely account for potential differences in cognitive biases over time, or at different time-points in viewing given stimuli. For example, with respect to the eye avoidance hypothesis in ASD, the underlying assumptions which predicate the theory do not take into account where attention is allocated when the eye region is avoided. The theory does account for a reduction in visual attention to the eye region, however does not demonstrate how visual attention changes over time and in its allocation outside of this region. More specifically, to say an individual avoided the eye region does not differentiate whether there was an active engagement of attention away from the eye region, or whether a more passive seeking of neutral information occurred instead. Looking to findings which show a reduction in eye movements (EM) made toward the eye region in ASD, a conclusion that the eyes were actively avoided may be supported; however, looking to findings which show an increase in EM toward the mouth region would instead seem to support a conclusion of passively seeking the neutral information (Neumann, Spezio, Piven, & Adolphs, 2006). Systematic avoidance of the eye region, regardless of its motivational foundations, may deprive an individual of important social information over time and maintain the eye-avoidant response. Considering the different factors which may drive the eye avoidance cognitive bias, it becomes difficult to conclude whether cognitive biases represent more active or passive adaptation on behalf of the individual.

Growing interest in the relationship between face processing and ASD has led to investigations of how cognitive biases might be specifically associated with the core social and emotional features of ASD. Several theories which explain the mechanisms involved in ASD symptoms and traits highlight how cognitive biases may lead to difficulty understanding, and unwillingness to seek out social information. A child with social difficulties who develops many negative associations, emotions, and responses to social stimuli may go on to struggle with social interactions later in life, and maintain further negative experiences. The maladaptive and protective factors which play into typical processing strategies, and how these factors may be atypical in ASD remain unclear. Researchers have suggested that the severity of ASD is associated with a reduced ability to understand the emotions and intentions of others (Ryan & Charragain, 2010). Further, face processing differences are also seen in individuals with subclinical levels of autism-like traits (Dickter, Burk, Fleckenstein, & Kozikowski, 2018). Largely, however, the manner in which the features of ASD and cognitive biases relate in autistic individuals and those with ASD traits is also unknown.

1.3.3 Cognitive Biases and Autistic Traits

The social impacts previously discussed in clinical ASD are often present in neurotypicals to varying degrees, manifesting as similar social and behavioral profiles to clinical presentations of ASD to a lesser degree of severity. An emerging framework for understanding ASD emphasizes that traits, behaviors, and tendencies relating to ASD are in fact present at varying degrees in all individuals; this view accounts for a transdiagnostic framework of addressing ASD traits outside of the conceptual structure of ASD diagnoses (Mandy, 2018). Formerly, ASD has previously been defined to span a collection of related disorders where individuals share a constellation of social and behavioral characteristics (American Psychiatric Association, 1994). ASD is currently characterized by the presence of persistent difficulties with social communication and interaction, in addition to restricted, repetitive patterns of behavior, with the inclusion of unusual sensory processing (American Psychiatric Association, 2013). Looking toward how social and behavioral profiles vary across a broader range of individuals, similar constellations of traits to those characterizing ASD can also be observed. More recently, cantilevered investigations have gone beyond this formal definition of ASD to examine how traits relating to ASD impact individuals who do not have clinical diagnoses. Studies including neurotypicals as participants have become increasingly common, adding a nuanced line of research to examine the mechanisms underlying the core features of ASD using a transdiagnostic approach. As our understanding of these mechanisms is currently unclear, so too is our understanding of which factors influence ASD traits and their impact to cognitive processing. Extending investigations to a broader range of individuals in order to compare cognitive biases along a more inclusive spectrum may indeed advance research into the factors which contribute to the core features associated with ASD.

Predicating the transdiagnostic view, research did identify individuals with a greater likelihood of displaying ASD traits. Early on, autism researchers noted a general constellation of social and behavioral features which could be seen more commonly among family members of autistic individuals compared to the general population. Relatives showed higher rates of social, cognitive, and behavioral differences, deficits, and/or tendencies which resembled those of autistic family members (Gerdts & Bernier, 2011; Kanner, 1943). ASD-related features included developmental delays, social difficulties, and atypical processing patterns (Kanner, 1943), alongside difficulties reciprocating social behavior, social communication, and restricted and repetitive behaviors (Constantino & Todd, 2003). A more modern approach to the dimensional view which categorizes individuals as autistic and nonautistic seeks to consider a continuous distribution of traits from those considered neurotypical through to clinical populations diagnosed with ASD (Constantino & Todd, 2003).

Various self-report tools have been developed to assess the level of ASD traits in individuals with and without diagnoses of ASD, which allows a continuous distribution of scores to be obtained along the broad spectrum of ASD features. ASD traits commonly assessed include poor planning skills and attentional inflexibility (Hughes, Leboyer, & Bouvard, 1997), a reduced ability to integrate information during processing (Stewart & Ota, 2008), and a weak central coherence or local processing bias (Happe & Frith, 2006). Previous evidence has shown there were no differences in the categorization of visual stimuli between neurotypicals with high and low levels of ASD traits, respectively, however higher traits corresponded with the tendency to rely less on prior perceptual knowledge to do so (Skewes, Jegindo, & Gebauer, 2015). Therefore, perceptual differences have been demonstrated, however visual biases more generally remain unclear. This difference in the use of priors to inform perception has been attributed to the modulation of perception by cognitive biases, such that processing strategies may vary as a function of ASD traits. Other evidence establishes the link between higher levels of ASD traits and atypical social processing in terms of cognitive perspective taking (Lockwood, Bird, Bridge,

& Viding, 2013). There is conflicting evidence to this link which suggests that ASD traits do not influence emotional processing in neurotypicals (Greene, Suess, & Kelly, 2020), and that emotional processing abilities are unimpacted in ASD (Lockwood, Bird, Bridge, & Viding, 2013). It therefore remains an outstanding challenge to disentangle how ASD traits might impact social, cognitive, and emotional processing in neurotypicals and along the continuum of ASD characteristics. Further, it remains unknown whether this information might be used to inform our understanding of ASD traits and features. Indirect evidence for the link between cognitive biases and ASD traits in neurotypicals might help to shed light on the current questions. Importantly, it might inform how commonly used paradigms and procedures might be adapted for use with a wide range of individuals, such that a more continuous distribution of ASD features can be investigated along a transdiagnostic view.

Chapter 2

2 Indices of Cognitive Biases

Perhaps due to the fact that they have been widely described across almost every aspect of human cognition, cognitive biases have similarly been measured across a myriad of paradigms and tasks. In Chapter 1, we have outlined broad processes which define and are hypothesized to give rise to cognitive biases. We now focus on the methods of measurement which have been commonly applied to investigate cognitive biases. Several ranging review studies have identified inconsistencies in cognitive biases across and even within common paradigms (Bar-Haim et al., 2007; Brooks, Prince, Stahl, Campbell, & Treasure, 2011; Cisler & Koster, 2010; MacLeod, Mathews, & Tata, 1986). These discrepancies have made it difficult to bring together a unified understanding of how cognitive biases impact social and emotional processing, let alone how the processes which give rise to them may impact our daily perceptions and cognitions. More difficult still is attempting to understand cognitive biases and their impact to individuals with major clinical, neurodevelopmental, and/or affective differences compared to neurotypical peers.

2.1 Tools to Measure Cognitive Biases

There are a number of common paradigms used to measure cognitive biases, considering the wealth of cognitive domains in which they have been observed. For the current assessment, we will focus on common procedures which have been used to measure cognitive biases for emotional faces.

2.1.1 The Dot-Probe Paradigm

The dot-probe paradigm is one of the most common tools used to assess cognitive biases in a variety of cognitive domains, including visual attention. Seminally published in 1986, the dot-probe paradigm was first described as a tool to measure cognitive biases by comparing differences in response latency to a visual target (MacLeod, Mathews, & Tata, 1986). A target, the *dot probe*, is typically presented on either side of a central fixation. Participants respond as quickly and accurately as possible by indicating the location of the dot probe. Importantly, before each appearance of the dot probe, a pair of task-irrelevant *distractor* stimuli are presented. In most versions of the dot-probe paradigm, emotional faces are included as the distractor stimuli to represent the true experimental manipulation; different responses to the dot probe as a function of the emotional faces which preceded it are commonly compared. One stimulus in the pair has a manipulated characteristic (e.g., emotional facial expression) which ostensibly induces biased processing toward or away from the image. Biases for the stimuli will impact response latencies during dot-probe trials in which the dot probe appears in the same location the distractor previously occupied. Response latencies will be faster for probes replacing the stimuli garnering the bias, if cognitive biases do exist to be measured.

For example, distractor pairs typically feature juxtaposed pairings of social and non-social stimuli, such as faces and objects, or social stimuli which vary in relevance, such as emotional and neutral faces. Previous evidence suggests that social information is preferentially processed in most neurotypicals (Morrisey, Reed, McIntosh, & Rutherford, 2018), therefore dot probes which appear in the previous location of a highly emotional face would be hypothesized to garner faster response latencies compared to a neutral face. Neurotypicals have been shown to display this pattern of cognitive biases during the dot-probe paradigm, with faster reactions for highly social and emotional stimuli (for a review, see van Rooijen, Ploeger, & Kret, 2017). Though our understanding of cognitive biases is currently limited by mixed findings, the dot-probe paradigm has arisen as the most commonly used measure of cognitive biases. Some researchers consider the dot-probe paradigm as the *gold standard* for research into biases in attention and other processes, given its high adaptability to different design parameters to address sources of cognitive biases.

2.1.2 Beyond the Dot-Probe Paradigm

The dot-probe paradigm is beneficial for widespread use because it is easy to conduct, and therefore should offer highly adaptable methodology. The added benefit of malleable task demands to allow participation from individuals with a range of cognitive abilities. However, the traditional dot-probe paradigm is somewhat limited by several factors. First, although the task is perhaps well-suited for use with a wide range of populations, a key issue for expanding use of the dot-probe paradigm with clinical populations is the fact that most paradigms incorporate highly social stimuli, which often featuring direct eye contact and/or gaze. For individuals with severe social anxiety or neurodevelopmental disorders which impact social abilities, highly social stimuli may be perceived as more threatening, aversive, or negative compared to neurotypical peers. Direct eye contact is particularly difficult for autistic individuals (Tanaka & Sung, 2016), which presents a problem for use with the dot-probe paradigm as direct eye contact can increase recognition and impact neural processing of emotions (Striano, Koop, Grossman, & Reid, 2006). Second, the dot-probe paradigm may be limited by a myopic measure of cognitive biases, in using only a single response time (RT) index. This latency to target detection therefore measures cognitive biases as an aggregate across trials of single points in time per trial, rather than a continuous stream of data. Further, the RT measure does not take into account whether participants make any changes in eye movements toward the stimuli, nor whether the stimuli are being captured in the visual field at all. Some researchers do incorporate task instructions which require eye movements, to ensure differences can be measured in attentional capture between the stimuli, (Valuch & Kulke, 2020), however the majority of dot-probe studies use the RT index as a freestanding measure of cognitive bias. Third, recent investigations have pointed out inconsistent findings across studies using the dot-probe paradigm, putting the gold standard nomenclature largely up for debate (e.g., Price, et al., 2015; Sears, Quigley, Fernandez, Newman,

& Dobson, 2019; Skinner, Olson, & Meltzoff, 2019; Thigpen, Forest Gruss, Garcia, Herring, & Keil, 2018). The dot-probe paradigm has been described to have low reproducibility and reliability (Waechter & Stolz, 2015; and for a review of the impact of low reliability on cognitive bias scores, see Rodebaugh, et al., 2016) which renders potential comparisons and adaptations to clinical populations a more difficult endeavor.

Considering these limitations, the dot-probe paradigm is perhaps not currently well-suited for use with autistic individuals, those who have disruptions to social abilities, who are very young, or struggle to comply with written and verbal instructions. Previous researchers have urged future studies to incorporate a combination of multiple methods to measure cognitive biases (Rodebaugh, et al., 2016), in order to address some of the limitations to reliability of traditional procedures. It is therefore appropriate to look beyond the dot-probe paradigm to procedures which might enhance the traditional measurements, or extend investigations into cognitive biases in individuals with a range of cognitive and social abilities. Further, given the wide variety of domains and populations along which they have been documented, it is important to examine whether the existing measurements may be consolidated. Given the limitations to use of the dot-probe paradigm with some clinical populations, we agree that multiple methods should be combined to address potentially substantive methodological concerns put forth about the validity and reliability of the task.

2.1.3 Eye Tracking

In light of these concerns, we sought to identify whether patterns of cognitive biases during the dot-probe paradigm could be replicated using concurrent eye tracking procedures. This aim may represent a move toward incorporating a naturalistic approach to measuring cognitive biases compared to the traditional dot-probe paradigm. Eye movements generally represent overt attentional processes more accurately compared to the covert attention required for downstream production of an RT response (Weirich, 1981). Eye tracking may therefore represent a measure of cognitive biases which more closely tracks various attentional processes underlying cognitive biases. Eye tracking has been incorporated more frequently to address some of the aforementioned limitations to RT-based procedures (Armstrong & Olatunji, 2012), including the dot-probe paradigm (Valuch & Kulke, 2020).

Eye tracking has been used to measure cognitive biases in individuals for whom the traditional dot-probe paradigm is perhaps inaccessible or inappropriate. For example, cognitive biases have been investigated with eye movements in infants (Leppanen, 2016) and young children (Kooiker, Pel, van der Steen-Kant, & van der Steen, 2016), individuals with PTSD (Kimble, Fleming, Bandy, Kim, & Zambetti, 2010), and autistic individuals with co-occurring depression (Bergman, et al., 2020). Eye-tracking tasks are especially useful for populations such as the non-verbal, the very young, or those with inhibited development because it allows for the translation of higher task demands into paradigms requiring little to no cognitive and social requirements. This may serve to reduce artifacts which can commonly populate cognitive bias research (Haselton, Nettle, & Murray, 2015). Measuring participants' eye movements for the duration of a stimulus viewing period, together with examining eye movements outside of this period, may offer a continuous stream of eye movement data to be related to RT-based cognitive biases within a predetermined stimulus viewing period.

Eye tracking measures of cognitive biases typically assess the difference in eye movements between social and non-social objects or between different kinds of emotional faces (Sears, Quigley, Fernandez, Newman, & Dobson, 2019), however reliability of these indices across different tasks remains relatively unclear (Waechter & Stolz, 2015). The preferential-looking paradigm, for example, is highly useful for investigating cognitive biases in infants, but more complex studies of the perception of emotion in adults often incorporate a cognitive demand to the task, such as RT measures in response to various stimuli (Sears, Quigley, Fernandez, Newman, & Dobson, 2019).

Eye tracking studies of cognitive biases typically consider three basic measurements, including whether there is a systematic bias in the initial allocation of gaze, i.e., the location of the first eye movement orientated toward the stimuli of interest. Additionally, bias can be measured as the maintained allocation of gaze, i.e., to the location of the most frequent eye movements. Another common measure of bias uses the duration of the total allocation of gaze, i.e., the location that received the longest duration of maintained eye movements. In essence, these measures are derived from the common investigation of the frequency and duration of eye movements to different areas of interest (AOI). Eye tracking analyses of cognitive biases using a combination of bias measurements with eye gaze allow for a more continuous view of how visual attention is allocated and may shift across a given stimulus presentation period. This approach may help to parse some of the processes which are hypothesized to underlie cognitive biases in early visual attention, from the processes which are associated with later perceptual biases. The current evidence supporting the use of eye tracking to measure cognitive biases is mixed, as many studies exert different parameters of experimental control with respect to eye movements, in addition to the issues with reliability in cognitive bias research which have been previously identified. Combining existing techniques to address some of the gaps which currently define our understanding of cognitive biases may offer insight into how RT-based and eye gaze measurements of early visual and later perceptual biases work concurrently and differently. Further, which aspects of the current methodology are indeed appropriate for a wider range of individuals, or which may have the potential to improve future investigations of cognitive biases are not well understood. We attempt to address these outstanding questions with respect to combining the dot-probe paradigm with concurrent eye tracking, in addition to going beyond the traditional dot-probe methodology toward more widely-appropriate measures of cognitive biases.

2.2 The Current Study

Due to the prevalence with which it has been implemented, the dot-probe paradigm has undergone innumerable variations (van Rooijen, Ploeger, & Kret, 2017). Across studies, there is mixed evidence as to whether the dot-probe paradigm is indeed useful for measuring cognitive biases and importantly, for the accurate measurement of group differences in cognitive biases between clinical participants and neurotypicals. One meta-analysis of studies using the dot-probe paradigm suggests that the currently mixed evidence may arise at least in part due to methodological differences (Bar-Haim, Lamy, Pergamin, Bakermans-Kranengurg, & van Ijzendoorn, 2007). Across studies, the researchers identified broad evidence for the moderating impact of clinical compared to neurotypical status, of procedural timing, and on stimulus modality on the measured RT effect.

Eye tracking studies of cognitive biases are gaining some momentum in the current literature; however, the findings as to whether group differences between ASD and neurotypicals in cognitive biases remain mixed. Percolating beneath the vast differences between studies are the potential for key methodological issues which would be beneficial to address. Given there are currently a dearth of studies controlling for eye movements during cognitive bias measurements such as the dot-probe paradigm, further research into combining these methods is required. Some consideration has been given to eye movements during the dot-probe paradigm, although few studies control for eye movements generally and fewer still measure them (but see Petrova, Wentura, & Bermeitinger, 2013). Stimulus onset asynchrony (SOA), or the time in between the appearance of the stimuli and the onset of the dot probe, has varied widely (SOA = 200-1250 ms) across different studies (Fox, Russo, Bowles, & Dutton, 2001; Sears, Quigley, Fernandez, Newman, & Dobson, 2019). These differences make it difficult to draw direct comparisons of cognitive biases, however shorter SOAs are typically incorporated to control for the number of eye movements possible during a given trial. In contrast, longer SOAs have been hypothesized to diminish or obscure the measurable RT effect of cognitive biases for emotional faces due to an increase the potential error variance (Petrova et al., 2013; van Rooijen, Ploeger, & Kret, 2017).

The intractable differences across studies and their associated findings make it difficult to consolidate a unified understanding of the processes underlying cognitive biases. In particular, differences in methodology such as longer SOAs, may lead to studies in which increased processing of a given stimulus represents cognitive bias, and other studies in which delayed disengagement of processing represents cognitive bias (Koster, De Lissnyder, Derakshan, & De Raedt, 2011). Changes in eye movements are hypothesized to precede changes in covert cognitive processing (Petrova, Wentura, & Bermeitinger, 2013), as visual attention is directed toward a given stimulus. It should thus follow that paradigms such as the dot-probe, which are assumed to provoke changes in cognitive processing style through the introduction of juxtaposed stimuli, should also produce dynamic eye movements between the stimuli. Consolidating these assumptions, cognitive biases measured using response latencies and cognitive biases measured using eye movements should reflect a similar pattern. However, with findings coming from studies addressing overt aspects of cognitive bias alongside covert biases which operate outside of cognitive awareness, these patterns remain difficult to align. Currently, few researchers control for eye movements during the dot-probe paradigm (but see (Petrova et al., 2013; Valuch & Kulke, 2020; Waechter & Stolz, 2015). For example, one study combined the dot-probe paradigm and eye tracking experiments to investigate cognitive biases, however this was conducted through distinct, rather than concurrent paradigms (Waechter & Stolz, 2015). This reflects back on the important underlying issue at hand, with respect to drawing conclusions about cognitive biases across individuals with a variety of cognitive and social abilities.

Although a modest number of studies have examined whether cognitive biases could be reliably measured using eye movements, little is known about how eye movements and thus directed visual attention impact cognitive biases across different methodologies, such as shorter and longer SOAs. As it stands, there is no solid evidence as to whether RT-based and eye movement-based measurements of cognitive biases are indeed assessing the same underlying construct. Taken together, there is some evidence for the association between increased cognitive biases, for example away from highly social information, and the core symptoms and traits associated with ASD. Other evidence suggests instead that autistic individuals can be less susceptible to some aspects of cognitive biases in rational thinking, and will exhibit less severe biases compared to neurotypicals (Morsanyi, 2010). Considering the lack of translational studies which directly compare cognitive biases in neurotypicals and autistic individuals, and the dearth of studies addressing sustained issues in comparing common methodologies, we examine the outstanding question of what role cognitive biases may play in social and perceptual abilities, especially as they relate to ASD.

2.3 The Current Objectives

In the current study, we dually attempted to validate existing measures of cognitive biases, and simultaneously address some of the overarching limitations to common paradigms used in neurotypicals and autistic individuals. We measured patterns of cognitive biases using RT-based and eye movement-based procedures concurrently, and then examined associations between the two measures and traits relating to ASD in neurotypicals. The general population shows a continuous distribution of ASD-related traits at varying degrees of severity; however, they are not debilitated by social and cognitive disruptions to the same level as some autistic individuals might be. Direct measurement of ASD traits allows some level of inference to be made about their association to cognitive biases, along the relatively continuous distribution of traits we anticipate to measure using a sample from general population. Accessing this type of population for the current investigation allows us to concurrently use two common procedures, the dot-probe paradigm and eye tracking, while still retaining some of the higher task demands (e.g., button press response to the location of a target) typically featured in the traditional dot-probe paradigm. Eye tracking elevates our ability to address cognitive biases further outside of the scope of a paradigm with high task demands, as it allows measurement of eye movements before the onset of the probe, and for the entire duration of a trial. We thus seek to consolidate some of the currently mixed evidence as to the role of cognitive biases in the social and cognitive features relating to ASD, in addition to how they might shed light on how common paradigms address issues with measuring cognitive biases.

2.4 The Current Design

To investigate cognitive biases in neurotypicals as they relate to ASD traits, we first employed two of the most common paradigms which are used to measure cognitive biases, the dot-probe paradigm and eye tracking. For the dot-probe paradigm, we also incorporated common methodological parameters as previously reviewed, including using different categories of emotional human faces as stimulus type, randomized and counterbalanced trial ordering between the emotions, and a relatively short SOA (200 ms). Using a shorter SOA controls for eye movements (van Rooijen, Ploeger, & Kret, 2017), and limits eye movements more closely in time to when the reaction time measures occurred. We derived RT bias scores from reaction times based on traditional procedures (MacLeod, Mathews, & Tata, 1986) between the two trial types (see Figures 1 and 2), which are described in detail in Chapter 3. Concurrent eye tracking was embedded within the dot-probe paradigm, which allowed for a continuous stream of eye movements to stimuli to be measured during the dot-probe paradigm trials. We further used eye tracking to allow for gaze-contingent trial control, such that it was ensured participants were viewing the screen prior to the start of each trial. We did not otherwise control for eye movements, in terms of the location or direction instructed prior to the paradigm.

From the dot-probe paradigm with concurrent eye tracking procedures, we derived two separate types of measurements for cognitive biases in our neurotypical sample. First, *RT Bias scores* were derived for each participant from the average response latency across all trials, and then used our eye tracking data to isolate response latencies across all trials in which eye movements were not made, to derive *RTn Bias scores*. Our assessments of the dot-probe paradigm trials with direct consideration of eye movements is a relatively novel approach (but see Petrova, Wentura, & Bermeitinger, 2013), which allows us to examine whether cognitive biases differ in the presence or absence of directed visual attention. Combination of the dot-probe paradigm with concurrent eye tracking therefore allows more information to be gathered about patterns in cognitive biases across time during the stimulus presentation period, toward and away from different stimuli, and even covert biases which might contribute to the RT measurement even in the absence of eye movements.

Chapter 3

3 Methods

3.1 Participants

An initial sample of neurotypical adults (*N* = 127; 90 females) with self-reported normal or corrected-to-normal vision was invited to participate through the undergraduate psychology research participant pool at the University of Western Ontario, in Canada. Participants provided written consent to take part in the study and were compensated with course credit (See Appendix A and B). Study approval was granted by the University of Western Ontario's Research Ethics Board.

Of the initial sample, data from 21 individuals had to be excluded listwise from further analyses due to eye tracker error (e.g., eye tracker malfunction, experimenter error, incomplete session). The final sample therefore included 106 participants (*N* = 72 females), who ranged in age from 17 to 46 years (with mean age M = 18.75 ± 3.14 years). We did not exclude participants on the basis of psychological diagnoses, based on the Research Diagnostic Criteria (RDoC) framework (Insel, et al., 2010). These criteria stipulate the inclusion of all individuals in studies relating to clinical symptomatology, to give a broad range and distribution of the variables of interest. Of our total sample, 18 participants disclosed they had previously received diagnoses for anxiety disorders, ten for MDD, six for ADHD, and two for obsessive-compulsive disorder (OCD). None of the participants self-reported having previous diagnoses of ASD, but we did not exclude individuals from participation on the basis of ASD diagnosis. The majority of our sample (*N* = 70) therefore disclosed no previous diagnoses of the major psychopathologies previously listed, and none reported diagnoses of psycho-affective disorders including schizophrenia, eating disorders, or personality disorders.

3.2 General Procedures

Participants completed an online self-administered questionnaire, which collected demographic information, in addition to a well-established measure of ASD traits. Participants then completed a single session of the dot-probe paradigm, the current gold standard for measuring cognitive biases to emotional stimuli, while reaction times and eye movements to the stimuli were recorded. We recorded these data to examine patterns of cognitive biases for different emotional faces, and related these biases to the presence and severity of ASD traits. We assessed ASD traits in our neurotypical population with the *a priori* expectations that trait levels would be approximately normally distributed in our sample, and that scores would correlate with a reduced, but not absent bias in the reaction time and eye movement data. Therefore, we hypothesized that emotional cognitive biases would be present in neurotypicals as has been previously discussed, but that the expected bias toward emotional compared to neutral faces would deviate in association with higher levels of self-reported ASD traits.

3.3 ASD Traits: The Autism-Spectrum Quotient

The Autism-Spectrum Quotient (AQ) is a 50-item self-report tool used to assess the presence and severity of broad traits relating to ASD (Baron-Cohen, Golan, & Ashwin, 2009; see Appendix C for the full questionnaire). The traits assessed together describe a constellation of tendencies, behaviors, processes, and responses which resemble those used to diagnose and classify ASD. Studies show that traits measured using the AQ could be found with a relatively normally distribution in the general population (Hurst, Mitchell, Kimbrel, Kwapil, & Nelson-Gray, 2007), and that commonly autistic individuals and their first-degree relatives will score higher on the AQ (Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010; Zhang, Fung, & Smith, 2019). Using the AQ, ASD traits were quantified according to sum scores from the total number of items on the questionnaire, and/or according to five subscale scores. The subscales consisted of 10-item collections, which together related to social skills (e.g., difficulty making new friends), attention switching (e.g., keeping track of multiple sources of conversation at the same time), attention to detail (e.g., noticing small features when others do not), communication (e.g., difficulty identifying and expressing emotions), and imagination (e.g., difficulty making up stories).

Items on the AQ were scored on a four-point Likert response scale, where endorsements of the item statements ranged from *definitely disagree* and *slightly disagree,* to *slightly agree* and *definitely agree* (Stevenson & Hart, 2017). Half of the total items were framed such that individuals with higher ASD traits would endorse the statement (e.g., *I find it difficult to work out others' intentions).* The remaining half of the items were framed such that individuals with higher ASD traits would disagree with the statement (e.g., *I find social situations easy*). Total scores were derived from the sum of all item responses, which allows for a maximum score of 150. The five subscales each had a maximum score of 30. Higher scores, for both total and subscale AQ measures, correspond to a greater degree of ASD traits. Cronbach's α for the test is .79 (Stevenson & Hart, 2017). Varied internal consistency has been measured between the five subscales (*social skills* = .75; *attention switching* = .61; *attention to detail* = .56, *communication* = .62, *imagination* = .46). The AQ has a high degree of specificity and sensitivity (each 95%) and has high test-retest reliability (R = .85).

3.4 Cognitive Biases in the Eye-Tracked Dot-Probe Paradigm

3.4.1 Materials

The dot-probe paradigm was presented to participants during a single session with 240 test trials. The session took place in a light-controlled room. A portable Tobii Pro X3-120 screen-based infrared eye tracker was used to track eye movements for the duration of the session. E-Prime software (version #3.0.3.60; Psychology Software Tools, 2016) and Tobii Pro software extensions (Tobii Pro, version #3.2) were used to communicate onscreen stimuli and record eye tracking data. Participants began the session seated approximately 60 cm away from a computer display monitor (Acer LCD, X223W) which had a refresh rate of 16.67 ms (60 Hz). The experimenter instructed participants to maintain a comfortable position with their heads on a chin rest, to control for large movements and changes in distance from the monitor. The eye tracker was affixed to the base of the monitor, operating at a sampling rate of 120 Hz. The experimenter performed guided calibration of the eye tracker for each participant, following a 9-point embedded calibration sequence to ensure accurate gaze capture. Participants completed practice trials orienting them to the requirements of the task, with no time limit.

Stimuli presented during the dot-probe paradigm consisted of 48 portrait-style images of people with an emotional facial expression, selected from the NimStim Set of Facial Expressions (Tottenham, et al., 2009). The NimStim database controls for the sex, age, race, and rated intensity of the expression for the images, which was counterbalanced across our selection. For each emotion type, we selected eight images each of angry, calm, fearful, happy, and sad expressions, alongside a control set of neutral faces. For test trials during the dot-probe paradigm, a neutral face was always paired with an emotional face, and the order of presentation of the faces and emotions was randomized across trials.

3.4.2 Procedures

See Figures 1 and 2 for graphical representations of the two types of dot-probe paradigm trials, with the dot probe appearing in the same location as the emotional or neutral face. Trials began after the calibration sequence, with participants pressing the space bar to instigate the start of the trial. During a trial, participants saw a white fixation screen. A black fixation cross was centrally located on the fixation screen (1 cm x 1 cm, or 0.95° of visual angle) identified as the AOI for this screen. Gaze-contingent trial control was implemented using the AOI such that participants could control inter-trial pacing by looking offscreen, and had to trigger the start of a subsequent trial by maintaining gaze toward the AOI for 400 ms. This method allowed us to control for attention capture at the start of each trial.

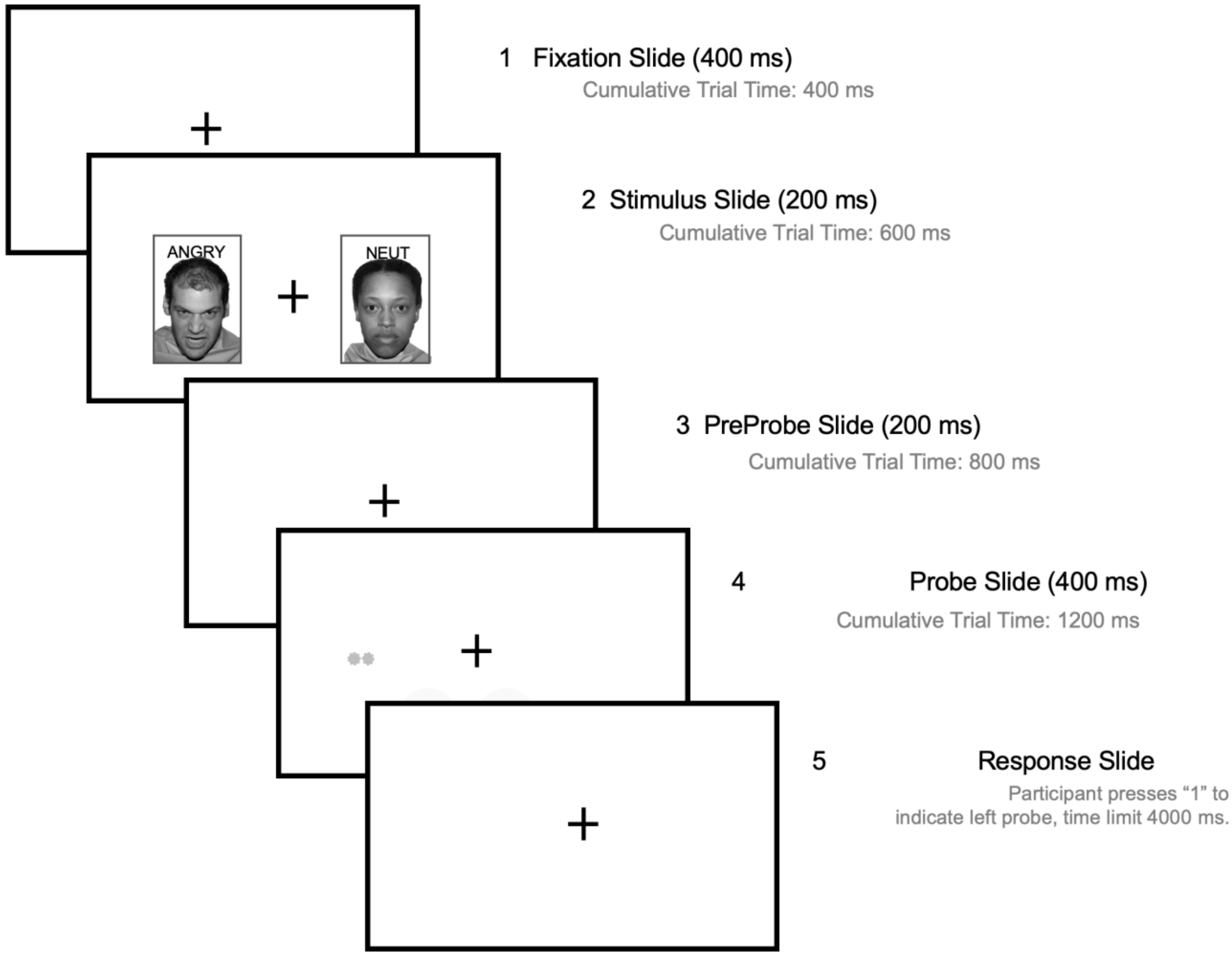

Figure 1. Graphical representation of an angry trial during the dot-probe paradigm with the dot probe appearing in the same location which previously held the angry face. Total trial time was > 1200 ms.

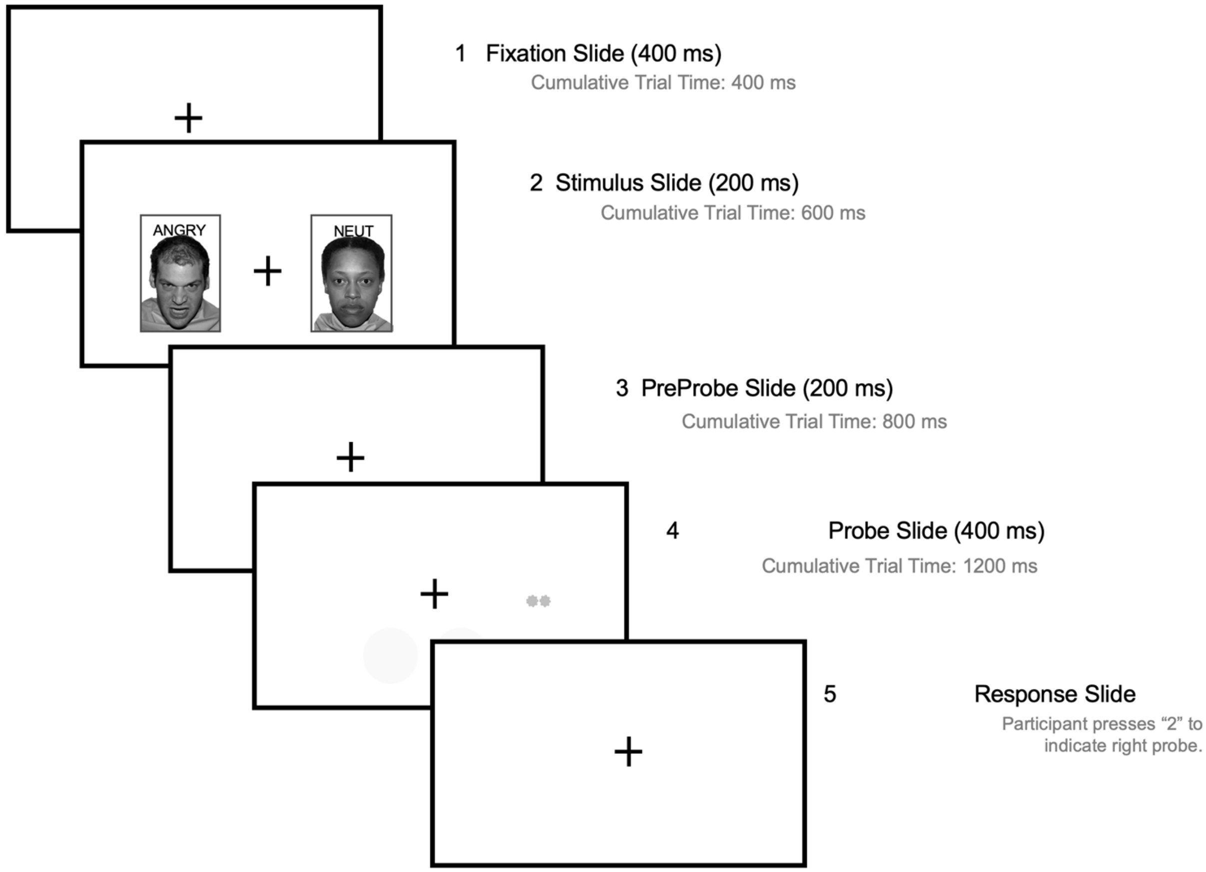

Figure 2. Graphical representation of an angry trial during the dot-probe paradigm with the dot probe appearing in the same location which previously held the neutral face. Total trial time was > 1200 ms.

Following the 400 ms fixation which triggered the trial, the stimulus screen was shown for 200 ms. Onscreen were two additional AOIs, arranged horizontally along either side of the central fixation cross. The stimulus AOIs each contained a neutral and emotional image, respectively (each 5 cm x 10 cm, or 9.53° of visual angle). We used the NimStim images without standardized luminance as they were derived from a set taken under consistent and strictly controlled viewing conditions. Offset of the stimulus screen was followed by the fixation screen (i.e., image offset) presented for an additional 200 ms. The probe screen was then presented, featuring the onset of the target stimulus for the RT cognitive bias measure. The probe consisted of a pair of dim, grey dots (0.25 cm diameter, arranged .25 cm apart, or 0.24° of visual angle) which appeared to either the left or right of the central fixation cross. Therefore, the probe was presented in the same AOI as either the neutral or emotional stimulus which was previously offset.

The location of presentation (i.e., either replacing the emotional or neutral stimulus) was counterbalanced across trials. Using the keyboard, participants indicated as quickly and accurately as possible whether the probe appeared to the left or the right of the central fixation cross. RT for probes in locations which previously had an emotional face in the same AOI were compared against RT for probes in locations which previously had a neutral face in the same AOI. This gave our first measure of cognitive biases for the different emotional faces, consistent with traditional procedures for the dot-probe paradigm (MacLeod, Mathews, & Tata, 1986). The RT bias scores were derived from the difference between these two trial types, on average and across the emotion types, meaning reactions to neutral and emotional faces were always being compared. Positive and larger RT bias scores therefore reflected the tendency across trials to respond in a biased manner, i.e., making responses more quickly to probes appearing in a location previously containing emotional information.

For the duration of the dot-probe paradigm session, we also collected eye movement data. We used the frequency and duration of eye movements allotted to each stimulus AOI, in addition to the same location for the AOIs until offset of the probe, to derive our second measure of cognitive bias. More frequent and longer eye movements to locations containing or previously containing emotional and neutral information therefore indicated the tendency to respond in a biased manner, i.e., spending more time looking at an emotional face and therefore responding faster to target information later presented in the same location.

3.4.3 Data Analyses

The present work investigated patterns of cognitive biases for emotional faces in neurotypicals, and examined the link between cognitive biases and the level of self-reported ASD traits. We considered the relationship between ASD traits and cognitive biases, in terms of how our measures relate to AQ scores. We then aimed to examine patterns of cognitive biases from our two indices, RT and eye movement data respectively, to determine if the indices were measuring the same underlying construct.

Under short stimulus presentation times, neurotypicals have been shown to reflect cognitive biases toward threatening information (Koster, Verschuere, Crombez, & van Damme, 2005). Given we used short presentation times and emotional faces, we predicted higher AQ scores to correlate with atypical cognitive biases, such that cognitive biases would be away from emotional faces, and/or toward neutral faces. Lower AQ scores were similarly expected to correlate with typical cognitive biases, such that there would be bias toward emotional faces, and/or away from neutral faces. Respectively, we conducted Spearman correlations between AQ scores and cognitive bias scores obtained from the dot-probe paradigm and eye tracking procedures. Kolmogorov-Smirnov normality tests were used to examine the distributions of scores and determine whether parametric or non-parametric tests were appropriate. We used an α value of .05 for p-values and corrected our bivariate correlations for multiple comparisons where appropriate using the Benjamini-Hochberg correction procedure. Corrected p-values equal to or less than .05 survived the procedure, $Q = .050$. Adjusted p-values for bivariate correlations which survived the correction procedure are reported respectively in the following sections.

Raw RT and eye movement data were exported from the E-Prime and Tobii software packages in Microsoft Excel spreadsheets (version 16.0). Raw data were preprocessed and analyzed using MATLAB (version 42.0), Python (Spyder version 3.3.0), and SPSS software (version 21.0). Given the 200 ms imbedded breakpoint between stimulus offset and probe onset (see *preprobe* in Figures 1 and 2), RTs which were less than 200 ms were already excluded from capture in the data collection. RTs greater than 1000 ms were later excluded as they represented responses slower than 600 ms beyond probe offset. Responses outside of this window would likely reflect inattention during the trial and potentially the failure to detect the target, and their exclusion is consistent with traditional procedures (MacLeod, Mathews, & Tata, 1986). From the raw RTs, data were retained from an average of 77.81 (S.D. = 8.75) trials per participant. Next, we derived our RT indices of cognitive biases from the dot-probe paradigm, per the traditional derived scores associated with the paradigm (MacLeod, Mathews, & Tata, 1986). RT Bias scores were calculated from the difference in RT between trials in which the neutral face and the dot probe appeared in the same location, and trials in which the emotional face and the dot probe appeared in the same location. These scores therefore reflected the average level and direction of cognitive bias in RT across trial types, which were parsed by emotion. Participants therefore each had five RT bias scores, one each for angry, calm, fearful, happy, and sad trials.

Eye movement data had been exported into prespecified eye movement parameters, defining gaze on a continuous basis within and without the bounds of the AOIs. Due to the relatively short SOA and stimulus presentation times (see (Koster, Verschuere, Crombez, & van Damme, 2005) we assessed the following commonly used indices for eye tracking cognitive bias studies (Fashler & Katz, 2014). We derived the number of trials in which the initial eye movement made on the stimulus screen was directed to one of the AOIs (i.e., first gaze following image onset to the neutral or emotional face), the proportion of eye movements made to the AOIs out of the total number of eye movements made during the full presentation period, and the proportion of time spent fixating to the AOIs out of the total duration of fixations for the full presentation period. Eye tracking measures were parsed for each emotion type, therefore measures of cognitive biases were derived from the difference in eye movement responses between emotional and neutral AOIs.

We derived total and subscale scores from the AQ which gave a continuous distribution of the presence and severity of ASD traits in our neurotypical sample. Pearson's and Spearman's correlations were conducted to determine whether associations could be found between our between-subjects factors, parsed by emotion. We used a within-subjects repeated measures design, with emotion and its five levels inputted as the within-subjects factor and cognitive biases and ASD traits with their total three levels inputted as between-subjects factors. An α value of .05 was used for the statistical tests. Planned comparisons included parametric and non-parametric comparisons of RT and eye movement-based cognitive biases with the measured ASD traits. Exploratory analyses were also conducted to further examine how our two measures of cognitive biases could be linked, with the aim of comparing trials in which eye movements were made to trials in which no eye movements were recorded to the AOIs.

3.4.4 Hypotheses

In samples from the general population, people tend to show cognitive biases toward emotional faces. When an emotional face is presented in direct visual competition with a neutral face, the emotional face is preferentially processed, either more or less, compared to the neutral face. This has been interpreted as cognitive biases in neurotypicals, and has been relatively well-documented as previously discussed. For samples from populations with major clinical and/or psycho-affective disorders, there is mixed evidence for whether individuals show cognitive biases for emotional faces (i.e., bias toward neutral or bias away from the emotion; (Bar-Haim, Lamy, Pergamin, Bakermans-Kranengurg, & van Ijzendoorn, 2007). Congruent with the findings which do establish cognitive biases toward emotional compared to neutral faces in neurotypicals, we expected our participants to show the same broad pattern of results. In particular, we expected the emotional faces to garner more attentional capture compared to the less salient neutral faces, given that we used a neurotypical sample. Within this broad pattern, however, we expected to find associations between cognitive biases away from emotional faces and higher levels of ASD traits. In short, we expected neurotypicals with higher levels of ASD traits to perform more similarly to autistic individuals compared to other neurotypicals with lower levels of ASD traits.

Cogent descriptions of ASD symptoms support the relationship between the social communication difficulties often observed in ASD and atypical sensory and emotional perception (American Psychiatric Association, 2013). We therefore expected our neurotypical participants to show cognitive biases for emotional faces in general, but that higher levels of ASD traits would correlate with cognitive biases for neutral, rather than emotional faces. The expected association between AQ scores and cognitive bias scores was predicated on the expectation that our cognitive bias measures were accessing the same underlying construct. Our *a priori* assumption of this association was tested by comparing cognitive bias scores between the measurements, and how they were associated with ASD trait levels. Specifically, participants with more cognitive biases for emotional faces would have lower AQ scores, respond faster to dot probes which replaced emotional compared to neutral faces, and look more toward emotional faces. Participants with cognitive biases away from emotional faces, or toward neutral faces would have higher AQ scores, respond faster to dot probes which replaced neutral compared to emotional faces, and look less toward emotional faces. Support for these hypotheses in the current study might suggest that ASD traits are associated with cognitive biases when viewing emotional faces in neurotypicals.

Chapter 4

4 Results

The present work investigated patterns of cognitive biases for emotional faces in neurotypicals, and examined the link between cognitive biases and the level of self-reported ASD traits. We predicted higher AQ scores would correlate with atypical cognitive biases (i.e., cognitive biases away from emotional faces, or toward neutral faces). In other words, our neurotypical sample would show in general cognitive biases for emotional faces to replicate standard dot-probe paradigm findings with neurotypicals, however those with higher ASD traits would show cognitive biases toward negative, or away from emotional faces.

4.1 ASD Traits and Cognitive Biases

4.1.1 AQ Scores

We first examined the level of ASD traits based on AQ scores obtained from our sample. We calculated total AQ scores alongside subscale scores for each participant. Responses to the 50 items were summed, and then averaged across participants to reveal a mean total AQ score of 62.83 (S.D. = 11.13, N = 101). Total scores ranged from 38 to 96, within the possible range of 0 to 150 (Stevenson & Hart, 2017). See Figure 3 for the distribution of total AQ scores. Subscale scores were summed from their respective 10 items, then averaged across participants to reveal mean AQ subscale scores of 10.41 (S.D. = 4.40) for social skills, 16.11 (S.D. = 3.86) for attention switching, 15.84 (S.D. = 3.73) for attention to detail, 6.29 (S.D. = 3.11) for communication, and 10.34 (S.D. = 3.73) for imagination. See Figure 4 for the distribution of mean AQ subscale scores. We conducted Kolmogorov-Smirnov tests of normality, which revealed the total AQ score ($D(101) = 0.06$, $p = .891$), and the five subscales followed an approximately normal distribution ($D(101) = 0.09$, $p = .387$ for social skills, $D(101) = 0.10$, $p = .228$ for attention switching, $D(101) = 0.10$, $p = .210$ for attention to detail, $D(101) = 0.09$, $p = .312$ for communication, and $D(101) = 0.10$, $p = .227$ for imagination.

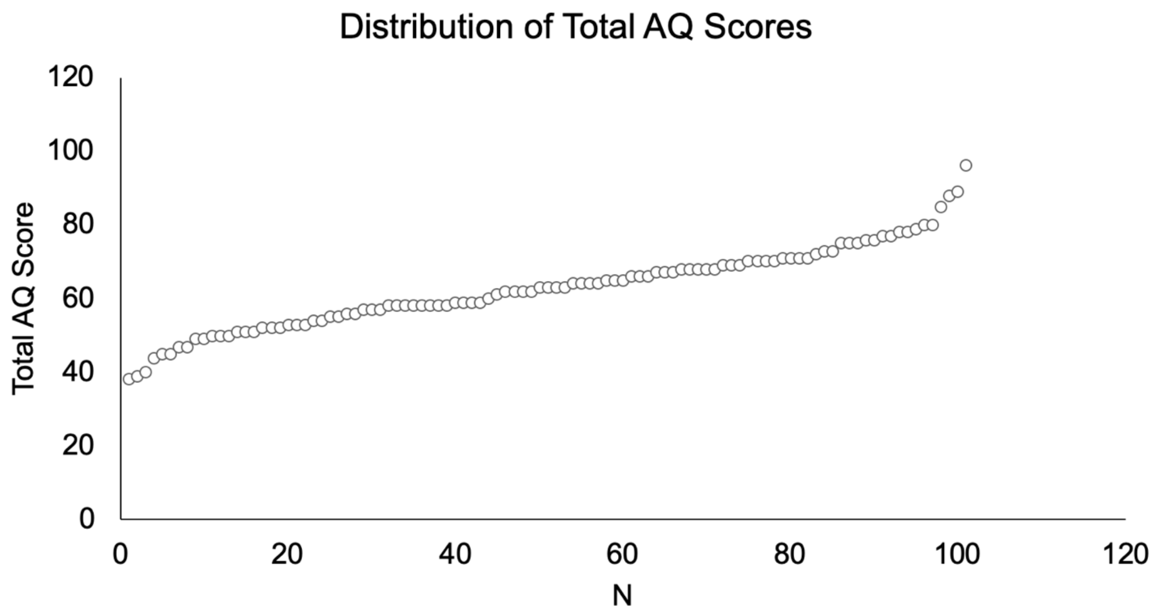

Figure 3. Distribution of AQ total scores for all participants who completed the AQ, N = 101. Scored of a possible range of 0 to 150. Mean score 62.83 (S.D. = 11.13).

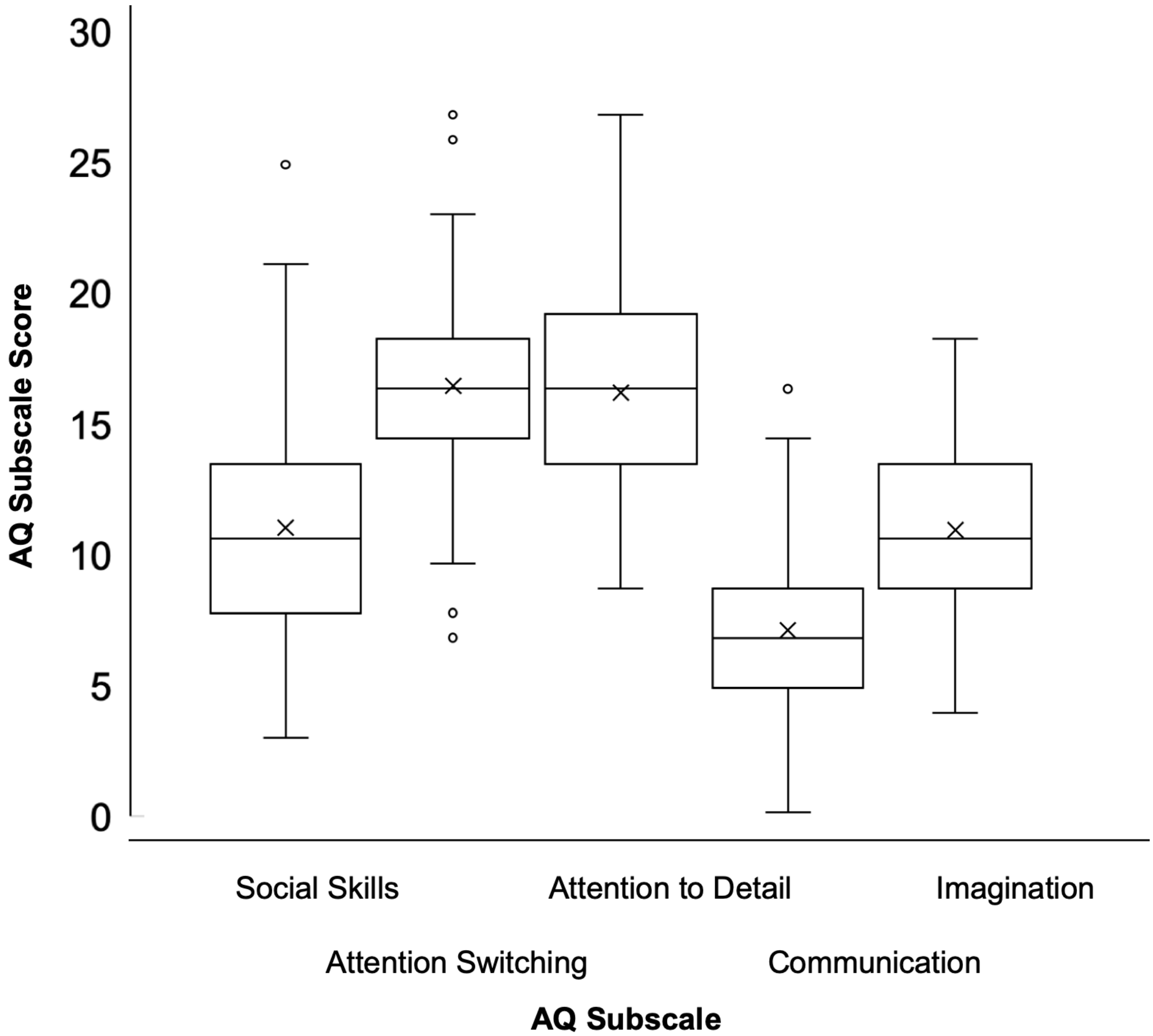

Figure 4. Comparison of mean AQ subscale scores for all participants who completed the AQ, N = 101. Possible range of scores 0 to 30. 'X' notation on the figure represents mean and error bars represent standard deviation (S.D.). Mean scores 10.41 (S.D. = 4.40) for *social skills,* 16.11 (S.D. = 3.86) for *attention switching,* 15.84 (S.D. = 3.73) for *attention to detail*, 6.29 (S.D. = 3.11) for *communication*, and 10.34 (S.D. = 3.73) for *imagination.*

4.1.2 Dot-Probe Paradigm Indices

The next step was to derive RT-based measures of cognitive biases from the dot-probe paradigm, per procedures described in association with the traditional task (MacLeod et al., 1986). Raw RTs were first extracted for trials in which the dot probe was correctly identified (i.e., accurate trials) between 200 ms and 1200 ms after its onset. On average, participants correctly identified the location of the probe during 77.81% (S.D. = 8.75) of the total 240 trials, above the generally accepted 75% cutoff for RT accuracy (e.g., Morales, Taber-Thomas, & Perez-Edgar, 2017). From these accurate trials, we calculated RT bias scores as the difference in RT between trials in which the dot probe appeared in the same location as the emotional face, compared to the location of the neutral face. RT bias scores were averaged across participants to reveal, by emotional category, mean scores of RT Bias Angry = 11.11(S.D. = 71.36, $N = 107$), RT Bias Calm = -16.41 (S.D. = 85.92), RT Bias Fear = 6.25, (S.D. = 72.09), RT Bias Happy = 0.35 (S.D. = 70.37), and RT Bias Sad = 11.03 (S.D. = 66.14). See Figure 5 for a graphical representation of RT Bias scores by emotion. We conducted Kolmogorov-Smirnov tests of normality, which revealed the RT Bias Angry score (D(101) = 0.12, $p = .075$), and the RT Bias Sad score (D(101) = 0.10, $p = .204$) did follow an approximately normal distribution, whereas the RT Bias Calm score (D(101) = 0.14, $p = .020$), the RT Bias Fear score (D(101) = 0.14, $p = .032$), the RT Bias Happy score (D(101) = 0.16, $p = .009$) did not follow a normal distribution.

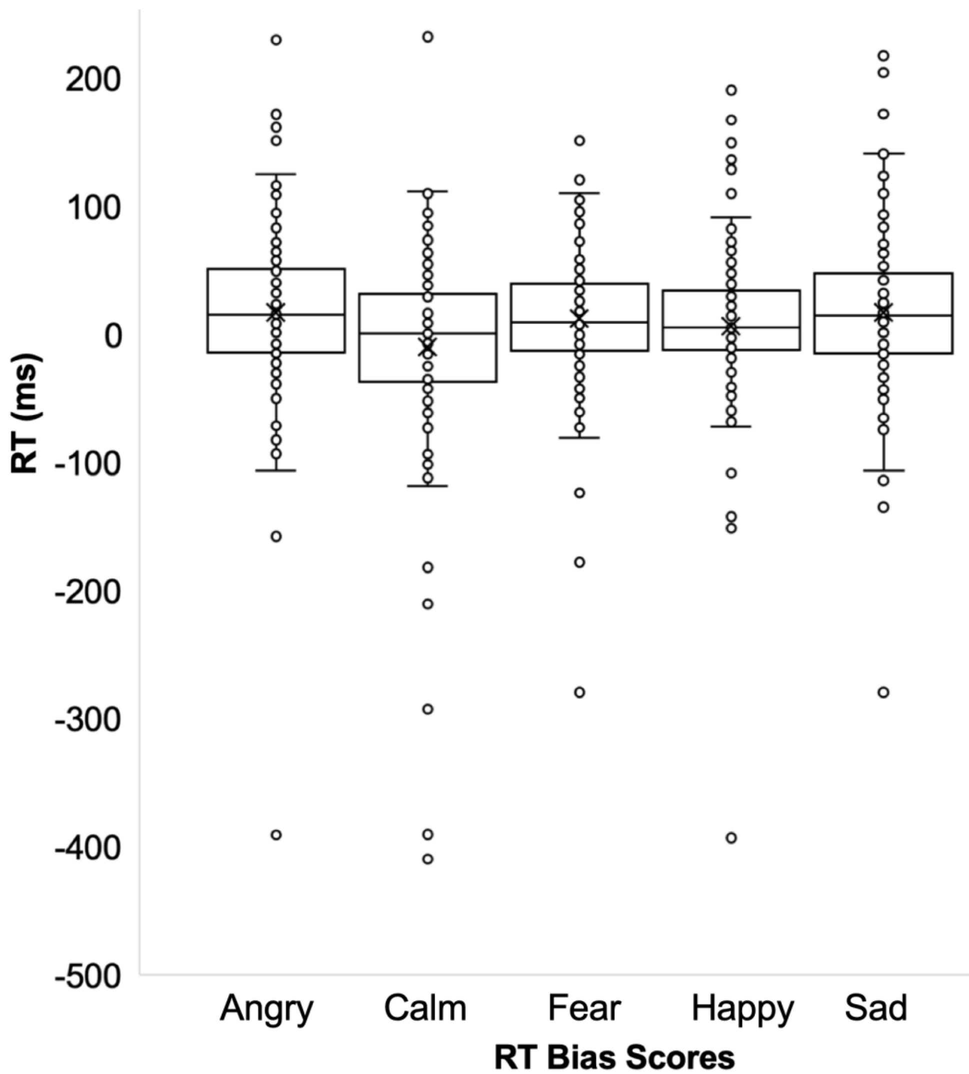

Figure 5. Distribution of mean RT Bias scores for all participants who completed the dot-probe paradigm, N = 107. 'X' notation on the figure represents mean and error bars represent standard deviation (S.D.). Mean scores RT Bias Angry = 11.11, S.D. = 71.36; RT Bias Calm = -16.41, S.D. = 85.92; RT Bias Fear = 6.25, S.D. = 72.09; RT Bias Happy = 0.35, S.D. = 70.37; RT Bias Sad = 11.03, S.D. = 66.14.

4.1.3 Eye Tracking Indices

We also recorded the frequency and duration of eye movements, according to previously used eye tracking parameters in conjunction with the dot-probe paradigm (Fashler & Katz, 2014). The number of initial eye movements and the duration of time with gaze directed to the emotional and neutral faces were compared as eye tracking indices of cognitive biases. We also examined the proportion of trials with eye movements made, of the total 240 trials. On average, participants made their initial eye movement to angry faces during 1.38 (S.D. = 1.88) trials, 1.26 (S.D. = 1.85) trials for calm faces, 1.28 (S.D. = 2.17) trials for fearful faces, 1.49 (S.D. = 2.11) trials for happy faces, and 1.26 (S.D. = 1.67) trials for sad faces through the full dot-probe paradigm session. On average, participants held gaze to angry faces for 806.56 ms (S.D. = 1079.43), 681.01 ms (S.D. = 1050.37) for calm faces, 805.12 ms (S.D. = 1124.65) for fearful faces, 1031.06 ms (S.D. = 4544.15) for happy faces, 915.62 ms (S.D. = 2304.80) for sad faces through the full dot-probe paradigm session. Results of the Kolmogorov-Smirnov normality tests revealed initial eye movements to angry faces were not normally distributed, D(107) = .30, $p < .0001$, to calm faces, D(107) = .25, $p < .0001$, to fearful faces, D(107) = .27, $p < .0001$, to happy faces, D(107) = .26, $p < .0001$, and to sad faces, D(107) = .27, $p < .0001$. The tests revealed also that the duration of gaze held to angry faces, D(107) = .22, $p < .0001$, to calm faces, D(107) = .26, $p < .0001$, to fearful faces, D(107) = .23, $p < .0001$, to happy faces, D(107) = .38, $p < .0001$, and to happy faces, D(107) = .34, $p < .0001$ were also not normally distributed. Across participants, eye movements were made to the left and right side of the screen during only 15.23% of trials (S.D. = 18.35), therefore each eye tracking measure was populated only by a small number of trials and eye movements. See Figure 6 for a graphical representation of the number of trials in which eye movements were made across participants.

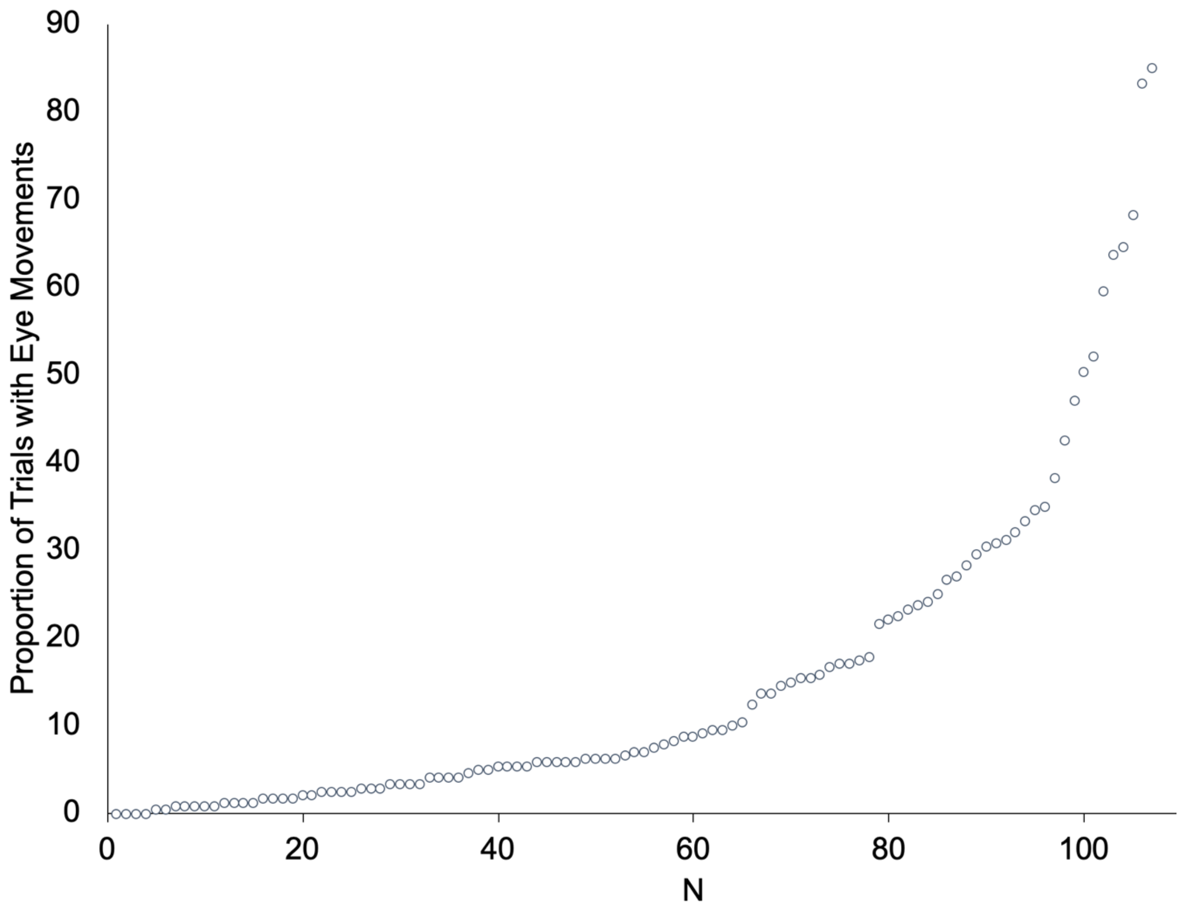

Figure 6. Frequency distribution of trials in which eye movements were made for all participants, N = 107. Proportion of eye movements of the total 240 trials; on average, eye movements were made during 15.23% of trials (S.D. = 18.35).

4.2 Correlating ASD Traits and Cognitive Biases

We used non-parametric Spearman correlations to assess the relationship between ASD traits and dot-probe paradigm indices of cognitive biases. Although some of the variables of interest did follow an approximately normal distribution, a number of the cognitive bias indices did not follow a normal distribution, and we opted to conduct the same type of correlations. See Numbers 1 to 11 in Table 1 for the full matrix of Spearman rank correlations between AQ total and subscale scores and RT Bias scores. RT bias scores for angry, calm, fearful, happy, and sad faces were not associated with total AQ scores nor subscale scores (range of Spearman's ρs = -

.163 to .131, *p*s = .101 to .925, *N* = 101). To summarize, we found no evidence of an association between AQ scores and RT bias scores for different emotional faces. We thus fail to support an association between ASD traits and dot-probe indices of cognitive biases in the current study.

Spearman correlations were also used to assess the relationship between ASD traits and eye movement indices of cognitive biases. See Table 2 for the matrix of Spearman rank correlations between AQ total and subscale scores and eye movement biases. Eye movement data revealed that there was an association between the initial eye movements made toward angry faces and scores from the attention to detail subscale, Spearman's $\rho = -.201$ $p = .048$. There was an association between the duration of time with gaze directed toward sad faces and scores from the attention to detail subscale, Spearman's $\rho = -.103$ $p = .020$. Finally, there was an association between the duration of time with gaze directed toward happy faces and scores from the attention switching subscale, Spearman's $\rho = .207$, $p = .042$. However, the majority of the eye movement indices for angry, sad, and happy faces and all of the indices for calm and fearful faces were not correlated with total or subscale AQ scores, Spearman's ρs < .01 to .99, ps = .100 to .999. Further, after correcting for multiple comparisons, the associations failed to survive the correction procedure (adjusted ps = .160 to .192). To summarize, we found no evidence of an association between AQ scores and eye movement cognitive bias measurements for different emotional faces. We thus fail to support an association between ASD traits and eye tracking indices of cognitive biases in the current study. Taken together, the results from the dot-probe paradigm and eye tracking indices of cognitive biases indicate no evidence to support a relationship between ASD traits and cognitive biases.

Table 1: Spearman's Rho (ρ) Rank Order Correlation Matrix Between ASD Traits and Dot-Probe Indices of Cognitive Biases (N = 101).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Total AQ	--	.000**	.000**	.000**	.000**	.000**	.654	.506	.436	.774	.925	.147	.433	.182	.370	.740
***2.** Social Skills*	.774**	--	.000**	.284	.000**	.194	.387	.592	.310	.652	.234	.069	.703	.042*	.593	.720
***3.** Attn Switching*	.630**	.423**	--	.191	.000**	.692	*.730*	.858	.250	.667	.650	.364	.087	.374	.839	.265
***4.** Attn to Detail*	.387**	.107	.130	--	.840	.419	.101	.136	.329	.770	.830	.504	.293	.704	.250	.366
***5.** Communication*	.692**	.720**	.362**	-.020	--	.040*	.179	.760	.188	.496	.908	.243	.625	.005**	.371	.540
***6.** Imagination*	.397**	.129	.040	-.080*	.203*	--	.439	.640	.350	.524	.617	.250	.416	.251	.053	.059
7. RT Angry	.045	.086	.018	-.163	.133	.077	--	.622	.032	.732	.561	.000**	.266	.005**	.961	.082
8. RT Calm	-.066	.053	-.114	-.148	.030	-.047	-.049	--	.744	.135	.273	.438	.000**	.796	.274	.794
9. RT Fear	.078	.101	.043	.097	.131	-.093	.212	-.033	--	.499	.015*	.326	.768	.000**	.488	.007*
10. RT Happy	.029	-.045	-.045	-.029	.068	.063	.034	.148	.067	--	.115	.980	.051	.542	.000**	.181
11. RT Sad	.009	-.118	.009	-.021	-.012	-.050	.058	-.109	.239**	.156	--	.574	.134	.112	.501	.000**
12. RTn Angry	.144	.137	.068	-.067	.116	.114	.886**	-.077	.098	.002	.056	--	.184	.125	.881	.316
13. RTn Calm	-.078	.038	-.169	-.105	.049	-.081	-.111	.892**	-.029	.192	-.149*	-.132	--	.904	.315	.883
14. RTn Fear	.132	.201*	.088	.038	.277**	-.114	.273**	.026	.771**	.061	.158*	.152	.012	--	.962	.019
15. RTn Happy	.089	-.053	.020	-.114	.089	.192	.005	.109	-.069	.711**	.067	.015	.100	.005	--	.685
16. RTn Sad	-.033	-.036	.111	-.090	.061	-.186	.172	.026	.266*	.133	.799**	.100	.015	.230**	.040	--
M	62.95	10.44	16.14	15.92	6.28	10.30	11.11	16.41	6.25	0.35	11.03	17.24	0.59	3.98	12.96	5.55
S.D.	11.05	4.38	3.85	3.80	3.10	3.38	71.36	85.92	72.09	70.37	66.14	51.78	57.91	51.81	53.34	46.85

Note. Associations between total AQ and subscale AQ scores, reaction time (RT) biases for trials with angry, calm, fearful, happy, and sad faces presented, and RT biases for trials in which no eye movements were made (RTn) with angry, calm, fearful, happy, and sad faces presented. Left and lower portion of the matrix shows *ρ,* Spearman's coefficient; right and upper portion of the matrix shows *p*, the unadjusted probability value. * represents $p < .05$, ** represents $p < .001$. M = mean, SD = standard deviation.

Table 2: Spearman's Rho (ρ) Rank Order Correlation Matrix Between ASD Traits and Eye Tracking Indices of Cognitive Biases (N = 101).

	7	8	9	10	11	12	13	14	15	16	17
1. Total AQ	.453	.873	.948	.939	.759	.903	.745	.682	.375	.110	.481
***2.** Social Skills*	.384	.400	.875	.600	.890	.402	.769	.665	.878	.562	.723
***3.** Attn Switching*	.068	.295	.850	.273	.311	.320	.224	.954	.165	.042*	.412
***4.** Attn to Detail*	.358	.048*	.856	.832	.999	.313	.367	.551	.831	.424	.020*
***5**. Communication*	.729	.802	.694	.453	.539	.360	.419	.795	.453	.524	.552
***6.** Imagination*	.343	.796	.121	.719	.689	.948	.704	.598	.864	.321	.878
7. Proportion EM Trials	--	.000**	.000**	.000**	.000**	.000**	.000**	.000**	.000**	.000**	.000**
8. First EM Angry	--	--	--	.000**	.000**	.000**	.000**	.000**	.000**	.000**	.000**
9. First EM Calm	--	--	--	.000**	.000**	.000**	.000**	.000**	.000**	.000**	.000**
10. First EM Fear	--	--	--	--	.000**	.000**	.000**	.000**	.000**	.000**	.000**
11. First EM Happy	--	--	--	--	--	.000**	.000**	.000**	.000**	.000**	.000**
12. First EM Sad	--	--	--	--	--	--	.000**	.000**	.000**	.000**	.000**
13. EM (ms) Angry	--	--	--	--	--	--	--	.000**	.000**	.000**	.000**
14. EM (ms) Calm	--	--	--	--	--	--	--	--	.000**	.000**	.000**
15. EM (ms) Fear	--	--	--	--	--	--	--	--	--	.000**	.000**
16. EM (ms) Happy	--	--	--	--	--	--	--	--	--	--	.000**
17. EM (ms) Sad	--	--	--	--	--	--	--	--	--	--	--
M	15.23	1.38	1.25	1.27	1.49	1.26	806.57	681.01	805.12	1301.15	915.62
S.D.	18.35	1.88	1.85	2.17	2.11	1.67	1079.43	1050.37	1124.65	4544.15	2304.80

Note. Associations between total AQ and subscale AQ scores and eye movement (EM) indices of cognitive biases. EM indices included the proportion of trials in which EMs occurred, the number of first EMs made, and duration of EMs (in ms) made to the angry, calm, fearful, happy, and sad faces. Left and lower portion of the matrix shows ρ, Spearman's coefficient, unreported values ρs = .313** to .850**; right and upper portion of the matrix shows p, the unadjusted probability value. * represents p < .05, ** represents p <.001. M = mean, S.D. = standard deviation.

4.3 Cognitive Biases: Task Performance

Our next goal was to look further into how participants performed the dot-probe paradigm. We were interested in the impact of the emotion presented on the patterns of cognitive biases measured. We also examined the presence and patterns of the eye movements we tracked during the dot-probe paradigm.

4.3.1 Effect of Emotion

To detect differences in RT as a function of the emotion presented, we conducted a non-parametric Friedman's test for a repeated measures analysis of variance using ranks. We found no evidence for differences in RT bias scores as a function of emotion, $X^2(3) = 2.12$, $p = .548$. The type of emotion presented did not significantly account for individual heterogeneity in our dot-probe indices of cognitive biases. Because some of the data did not follow a normal distribution, a Wilcoxon signed-rank test was conducted. Results from the Wilcoxon test indicated the median score of RT Bias Angry and RT Bias Sad scores were significantly higher than a median score of 0, with Mdn = 10.96, Z = 3758.00, $p < .012$ and Mdn = 10.04, Z = 3603.50, $p < .043$ but were not different from one another. The median score of RT Bias Calm, RT Bias Fear, and RT Bias Happy were not higher than a median score of 0, with Mdn = -5.07, Z = 2532.50, $p = .208$, Mdn = 4.52, Z = 3371.50, $p = .189$, and Mdn = -0.22, Z = 3139.00, $p = .548$ respectively. In general, our RT Bias scores did not significantly differ from a hypothesized median of 0.

4.3.2 Effect of Eye Movements

We previously reported participants made eye movements during only 15% of the dot-probe paradigm trials. Overall, several participants made no eye movements to either the left or right side of the screen during the entire dot-probe paradigm session. Thirty-five more participants made no eye movements to either locations during 95% or more of the total 240 trials, and an additional sixty participants made eye movements to either location during 50% or fewer of the trials. Eight participants did make eye movements more than 50% of the time. The low number of eye movements and the high RT accuracy together show that accurate performance on the dot-probe paradigm was not significantly impacted by participants failing to make an eye movement to either side of the screen. Given our sample performed above the 75% accuracy cutoff yet made so few eye movements, eye movements toward the probe may not have been required for probe detection with acceptable accuracy. Together, our second main result was that we found no differences in cognitive biases as a function of the emotion presented, and few eye movements were made during the dot-probe paradigm in general despite accurate performance.

4.4 Cognitive Biases: Concurrent Measures

After examination of the previous dot-probe paradigm and eye tracking measures of cognitive biases and their association with ASD traits from the AQ, we also wanted to determine how the two measurements might be consolidated. Participants made eye movements to the left and right side of the screen during only 15% of the total number of trials, meaning that a majority of the data which populates our RT bias scores comes from trials in which no eye movements were made. Therefore, we explored how our eye tracking procedures might be used to better understand how participants performed during the dot-probe paradigm. We may not make direct conclusions about the eye movements measured per se, considering the low number overall made during the dot-probe paradigm. However, we can explore trials in which participants were not looking at the stimuli. The exploratory cognitive bias measure is thus informed by our use of eye tracking, but we isolate cognitive biases to represent only covert biases in the absence of overt visual attention (i.e., allocated gaze) toward the stimuli.

Given the relatively low number of eye movements made across all participants and trials, and the spurious relationships between our derived cognitive bias scores and ASD traits, we explored the association between our cognitive bias measures to determine whether they were assessing the same underlying construct. Eye movements have been shown to impact RT-based measurements of cognitive biases, where gaze occurring prior to probe onset can diminish or obscure the measured RT effect (Bradley, Mogg, & Millar, 2000; Petrova, Wentura, & Bermeitinger, 2013). Given the distribution of trials in which eye movements were made compared to those in which no eye movements were made, we sought to exclude trials with eye movements from the exploratory analyses. Although participants who failed to make eye movements during a majority of trials did not perform the dot-probe paradigm as expected, this may help to explain why RTs were not impacted by emotion but the average performance of our sample in terms of RT-based accuracy was above the accepted 75% cutoff.

We analyzed the exploratory *RTn Bias Scores* for trials in which no eye movements were made, using the same procedures as the RT Bias scores for all trials regardless of eye movements. By emotion type and averaged across participants, our data revealed an average of RTn Bias Angry = 17.24 (S.D. = 51.78), RTn Bias Calm = 0.59 (S.D. = 57.91), RTn Bias Fear = 3.98 (S.D. = 51.81), RTn Bias Happy = 12.96 (S.D. = 53.34), and RTn Bias Sad = 5.55 (S.D. = 46.85). We conducted Kolmogorov-Smirnov tests of normality, which revealed the RTn Bias Calm score (D(101) = 0.09, p = .311), the RTn Bias Fear score (D(101) = 0.12, p = .050), and the RTn Bias Sad score (D(101) = 0.07, p = .542) did follow an approximately normal distribution, whereas the RTn Bias Angry score (D(101) = 0.13, p = .035) and the RTn Bias Happy score (D(101) = 0.13, p = .035) did not follow a normal distribution.

To mirror aspects of the previous analyses, we also used Spearman correlations to examine the association between ASD traits and dot-probe indices of cognitive biases when participants made no eye movements during the trials (see Figure 7). See Numbers 1 to 6 and 12 to 16 in Table 1 for the matrix of Spearman rank correlations between AQ total and subscale scores and RTn Bias scores for trials without eye movements. RTn bias scores for angry, calm, happy, and sad faces were not associated with total AQ scores nor subscale scores (range of Spearman's ρs = -.186 to .192, *p*s = .053 to .839). RTn bias scores for fearful faces, however, were associated with scores from the *social skills* (Spearman's ρ = .201, *p* = .042) and the *communication* subscales (Spearman's ρ = .277, *p* = .005). After correcting for multiple comparisons, only the correlation between RTn bias scores for fearful faces and scores from the *communication* subscale survived the procedure, adjusted *p* = .03. Given the outsized contribution to our overall dot-probe paradigm data from trials in which no eye movements were made, the exploratory results unsurprisingly mirror the same spurious trends as the overall RT Bias scores. Taken together, the findings show no evidence overall for the association between ASD traits and cognitive biases for different emotional faces.

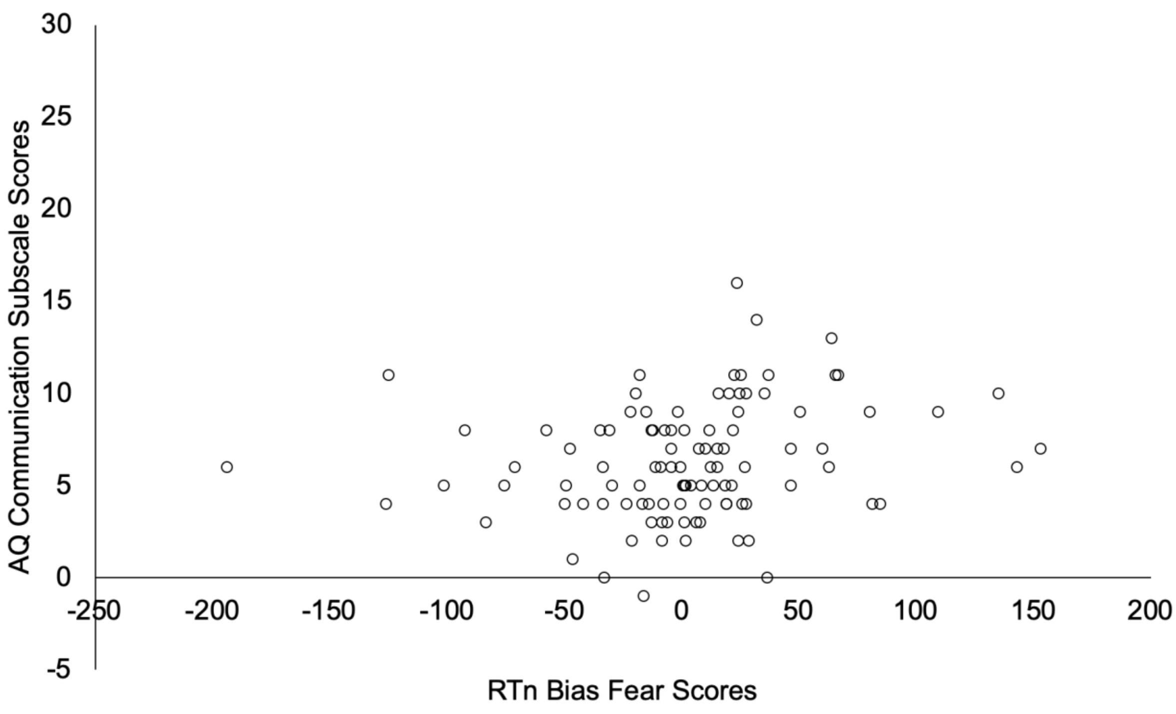

Figure 7. Scatterplot showing the spurious association between AQ Communication Subscale Scores RTn Bias Fear scores. After correction for multiple comparisons, adjusted *p* = .03 (*N* = 101).

Chapter 5

5 Discussion

The current study investigated whether ASD traits and cognitive biases for emotional faces were linked in neurotypicals. We used the dot-probe paradigm with concurrent eye tracking to relate self-reported ASD trait levels with two measures of cognitive biases, and to assess whether the two measures were assessing the same underlying construct. First, we found no evidence to support a relationship between ASD traits and cognitive biases both in terms of dot-probe and eye tracking indices. Second, our results showed there were no differences in cognitive biases as a function of the emotion presented, and that very few eye movements were made during the dot-probe paradigm across the majority of participants. Third, when we excluded dot-probe paradigm trials with eye movements, we again found no evidence to support a relationship between ASD traits and RT indices of cognitive biases. We outline and contextualize our findings within the extant literature, and discuss the potential contribution of our design to further investigations of ASD traits and cognitive biases.

5.1 The Relationship Between ASD Traits and Cognitive Biases

One of the primary goals of the study was to address the relationship between ASD traits and cognitive biases for emotional faces. Our first overarching result was that we found no evidence to support a relationship between ASD traits and cognitive biases using either of our cognitive bias measures. As a first step to address our goal, we assessed the level of self-reported ASD traits with the expectation that our neurotypical sample would score a roughly normal distribution of traits on the AQ (Ruzich, 2015). Total AQ scores did follow an approximately normal, continuous distribution, supporting that our sample was likely representative of the general population in terms of ASD traits. The second step to address the goal was to relate the level of ASD traits with our two measures of cognitive biases. There is currently mixed evidence from both dot-probe and eye tracking indices of cognitive biases as to how they are impacted as a function of ASD. However, a large body of evidence does establish that emotional stimuli are more salient, more accurately processed, and more quickly attended to compared to neutral stimuli in paradigms such as the visual search and dot-probe paradigms (MacLeod, Mathews, & Tata, 1986). Taken together, this evidence lends itself to our *a priori* expectation that higher ASD trait levels would correspond to atypical cognitive biases, such that participants with higher ASD traits would show cognitive biases away from emotional faces, or toward neutral faces as the emotional faces would be interpreted as more threatening. Contrary to our expectations, in the present study, no relationship was found between the level of ASD traits and cognitive bias measures from the dot-probe or eye tracking indices. We further dissect the current understanding of cognitive biases by isolating evidence from each of our two measures.

5.1.1 The Dot-Probe Paradigm

Given no relationship could be found between ASD traits and RT scores obtained from the dot-probe paradigm, our results somewhat support previous evidence in which no differences in cognitive biases could be measured as a function of ASD traits (Greene, Suess, & Kelly, 2020; Hollocks, Ozivadjian, Mathews, Howlin, & Simonoff, 2013; Monk, et al., 2010). This would seem to support the idea that the mechanisms which dictate the automatic aspects of face processing can be unimpacted even in association with ASD characteristics. It is possible we failed to find a relationship between ASD traits and cognitive biases due to relatively short stimulus presentation times (200 ms), however other studies using neurotypicals have shown threat biases may be measured even at 100 ms presentation rates (Koster, Verschuere, Crombez, & van Damme, 2005). One study reported there were no cognitive biases for emotional faces in ASD, but they were uninterrupted in neurotypicals (Moore, Heavey, & Reidy, 2012). Our findings therefore go against what we would expect based on dot-probe paradigm evidence in which there are face processing differences between neurotypical and clinical ASD groups, however, they do fit with several studies which found no differences in cognitive biases related to ASD traits.

5.1.2 Eye Tracking

With respect to previous eye tracking studies of cognitive biases, the current results align with recent findings in which no differences were observed as a function of ASD traits (Greene, Suess, & Kelly, 2020). However, our finding goes against what we might expect based on the known difficulty processing faces associated with clinical ASD (Swanson, Serlin, & Siller, 2013; Swanson & Siller, 2014), and the extension of ASD traits within the general population. The finding of no relationship between ASD traits and cognitive biases in the current study is thus supported by some of the existing evidence, however, goes against our expectation that we would see the face processing difficulties often reported in ASD extend to those with ASD traits. The low number of eye movements made in addition to the neurotypical sample may together help to explain one reason why we failed to find a relationship between ASD traits and cognitive biases. Eye tracking paradigms have previously been used to show some of the complex features of ASD (Falck-Ytter, Bölte, & Gredebäck, 2013), and that ASD has been associated with cognitive biases in more automatic aspects of attention for social scenes (Santos, et al., 2011). In line with our expectations of cognitive biases for emotional compared to neutral faces in the RT portion of the dot-probe paradigm, we expected similar patterns with our eye tracking measures. Specifically, we predicted participants would look longer and more frequently at emotional compared to neutral faces, but that for those with high ASD traits, they would show neutral and not emotional biases in general and look more at the negative and not positive faces. In light of the profound social and face processing difficulties often reported by autistic individuals, there may be differences in cognitive biases and face processing which the current methodology fails to detect, however further research is required to determine whether cognitive biases are impacted in individuals with ASD traits.

5.2 Cognitive Biases: Task Performance

Another goal we addressed was to shed light on the patterns of cognitive biases while participants performed the dot-probe paradigm. Our second overarching result was that we found no differences in cognitive biases as a function of the emotion presented, and few eye movements were made during the dot-probe paradigm in general. Consistent with the hypothesis that the emotional factors of a stimulus play a role in active gaze (Niu, Todd, & Anderson, 2012), and the standard result of the dot-probe paradigm reflects bias toward threat-relevant locations (MacLeod, Mathews, & Tata, 1986), we expected to find cognitive biases for emotional compared to neutral faces. Our data did not reflect a relationship between ASD traits and cognitive biases. The specific emotion presented was not related to differences in the level of cognitive bias shown, in terms of RT or eye movement indices. These findings do not align with previous evidence supporting that adults tend to bias away from negative faces in favor of positive faces (Bradley, Mogg, & Millar, 2000). Our results do however align with previous findings in no difference in processing of neutral and emotional faces were found, where children showed no cognitive biases for angry, sad, or happy faces (Garcia-Blanco, et al., 2017), nor for faces displaying disgust (Zhao, Zhang, Fu, & Maes, 2016). Therefore, it seems cognitive biases for different emotional faces are not fully understood in terms of how they present across the lifespan, nor in the role different emotions play in the direction and magnitude of cognitive biases. Our findings contribute to the currently mixed evidence surrounding ASD traits and cognitive biases.

Interestingly, when we examined the number of eye movements actually made during the trials, participants made eye movements on average during only 15% of all trials. This means that the RT measure of cognitive biases was populated primarily by trials in which no overt attention was directed toward either the emotional or neutral face or the dot probe. Despite the overall dearth of eye movements from our sample during the dot-probe paradigm, we wanted to use the concurrent eye tracking and dot-probe paradigms methodologies to better understand how participants were performing the task. Considering the usable eye tracking data was therefore lacking, it is difficult to conclude whether there was covert attention paid to the stimuli in the absence of eye movements (Anderson & Yantis, 2012), and whether this would have impacted subsequent reactions to the dot probes. It is possible that the emotional faces were not salient enough compared to the neutral faces, however we selected faces which had received at least 85% ratings in terms of recognizability and intensity of the emotion from previously validated raters (Tottenham, et al., 2009). Another reason for the relatively small number of eye movements made during the dot-probe paradigm may have been due to the gaze contingent trial control we used to structure and control for attention at the start of the trial. With eye gaze required to be maintained to the central fixation cross for 400 ms at the start of each trial, it is possible participants resorted to remaining fixated for the duration of the trial on the fixation cross. However, participants were only instructed that the maintained eye gaze would trigger the start of the trials and that pictures and targets would appear; further, without the gaze contingency, the current methodology would not be useful to measure cognitive biases in very young or socially and verbally disadvantaged individuals given the relative importance of eye movements to faces. Further, the relatively high accuracy retained in terms of detecting the dot probes indicate that there was not necessarily a lack of attention to either the left or right side of the screen, where the faces and probes appeared.

Previously, researchers have explicitly instructed participants not to view the stimuli (Waechter & Stolz, 2015; Valuch & Kulke, 2020), in order to specifically measure covert attention biases. We replicated this in our exploratory analyses, by excluding trials in which eye movements were made. Therefore, the patterns of cognitive biases which we measured necessarily fit better with previous studies of covert attention to emotional faces, as opposed to the majority of dot-probe paradigm studies which do not control for eye movements. Without the use of concurrent eye tracking, participants' accuracy on the dot-probe paradigm would have been measured without knowing how participants were actually performing the task, which was in general to make no eye movements to the stimulus locations onscreen. Although our results are generally trending in the expected manner and we did find several spurious correlations between ASD traits and cognitive biases, a majority of the data making up the RT-based measure of cognitive biases was therefore coming from trials in which eye movements were not made. Researchers have previously identified the impact of eye movements to measured cognitive biases, in which eye movements occurring prior to the onset of the dot probe can obscure or diminish the RT effect of interest (Petrova, Wentura, & Bermeitinger, 2013). Further, as participants did not make many eye movements during a majority of the dot-probe paradigm trials, we cannot conclude whether cognitive biases were representative of vigilance for the positive emotions, or from difficulty disengaging attention from the location in which emotional stimuli previously appeared. Although there were few biases seen across our sample altogether, individual differences in cognitive biases gave a continuous distribution with which to run correlations with our ASD trait measure (see Figure 5). Further investigations of cognitive biases should exert control over the eye movements permitted during face processing tasks. Additionally, eye tracking should be used to help examine where participants are looking during the dot-probe paradigm. This adaptation to the current methodology would contribute to our understanding of cognitive biases and how they are informed by eye movements, which is needed to further disentangle the processes which give rise to cognitive biases. A key benefit of using eye tracking procedures is that they are relatively unobtrusive and internally methods which can be easily adapted for use across a wide variety of individuals, who have a wide range of abilities. This aspect of the current methodology should therefore be retained to the benefit of autistic individuals in future studies of cognitive biases.

5.3 Cognitive Biases: Concurrent Measures

The final goal of the current study was to investigate the relationship between two concurrent but distinct measures of cognitive biases, the dot-probe paradigm with eye tracking. Our third overarching result was that comparisons of our measures gave little evidence to support a relationship between the dot-probe paradigm and eye tracking indices of cognitive biases, given that we could exclude dot-probe paradigm trials in which eye movements occurred. We were curious as to whether eye tracking would lend itself to provide a more accurate, appropriate measure of cognitive biases which could be later compared to previous findings, making the design more suitable for individuals with cognitive, social, and/or verbal difficulties compared to the traditional dot-probe paradigm. The current study addressed a first step toward adapting widely used procedures for autistic individuals, by examining whether the patterns of cognitive biases measured using the dot-probe paradigm and those measured through eye tracking were indeed comparable in terms of how they related to ASD traits. When we examined the patterns of cognitive bias from our two measures, we found our results did not support the relationship between our RT-based and eye movement-based measures of cognitive biases for emotional faces. The dot-probe paradigm has been previously combined with concurrent eye tracking, for example in individuals with chronic pain (Fashler & Katz, 2014). In their study, participants completed the dot-probe paradigm while eye movements were recorded, to reveal while the RT indices showed no cognitive biases, the eye movement indices showed cognitive biases toward pain-related stimuli. In another study with neurotypicals as participants, anxiety traits were not found to be associated with cognitive biases from the dot-probe paradigm, but were associated with cognitive biases measured using eye movements (Veerapa, et al., 2020). Despite the fact we did not find a relationship between our two indices of cognitive biases, we suspect this may be in large part due to the lack of eye movements made in general. However, when isolating the RT measure to only include trials without eye movements, the RT effect again produced only spurious relationships with ASD traits. The current methodology may yet be used to better inform future investigations of face processing as a function of ASD traits. Namely, how performance on the cognitive task may be better understood in light of a concurrent, continuous stream of data regarding where participants look in future tasks.

Although there was an outsized number of trials during which no eye movements were made, this was perhaps not an inherent limitation of the current methodology. We used a neurotypical sample, and gave no instructions to specifically attend to or look at the emotional or neutral face stimuli. It is therefore perhaps not surprising that we had a relatively small range of ASD traits, few to no participants with very high trait levels, and few participants who made a large number of eye movements to the emotional and neutral faces. In the absence of eye movements, however, it becomes exceedingly difficult to draw a meaningful conclusion about overt cognitive biases using eye tracking.

This presents a key methodological impasse for researchers attempting to consolidate existing measures of cognitive biases in more accessible and translatable ways for autistic individuals, and those of lower ages, and cognitive and verbal abilities. Further research is needed to identify whether cognitive biases can be reliably measured in participants in the absence of verbal instructions or task demands, in order to make measurements of cognitive biases more naturalistic and appropriate for these populations. Because the traditional dot-probe paradigm does require a degree of cognitive capacity to respond to instructions and onscreen task demands, it renders the paradigm potentially unsuitable for some individuals on the autism spectrum (Burris, Barry-Anwar, & Rivera, 2017). If instructions and task demands are also required for eye tracking studies of cognitive biases, and if eye movements may not occur even with these controls in place, perhaps these paradigms are also unsuitable for some individuals on the spectrum. Artifacts in research methodology are indeed common to some investigations of cognitive biases (Haselton, Nettle, & Murray, 2015), and the current study aligns with this explanation of our two significant correlations which did survive correction procedures, given the overarching lack of supporting or similar evidence our of comparisons. At present, it appears that some other way of ensuring eye movements to stimuli is required, in a manner that would not be inherently disturbing, threatening, or off-putting to an autistic or non-autistic individual.

It appears there are further limitations to adapting the current methodology for use with individuals with reduced cognitive, social, and/or verbal abilities considering the two measures were not related. Perhaps the dot-probe paradigm and eye tracking indices were indeed accessing different constructs, namely that the dot-probe paradigm measure derives a bias score based on a single response during a trial, whereas eye tracking offers a larger picture of the initial and maintained visual attention during an entire trial. The current study is thus limited by the lack of eye movements made in our ability to draw conclusions based on overt visual attention, however, does inform how RT-based and eye movement indices of cognitive biases might be compared in future studies.

5.4 Conclusions

It is imperative to better understand the mechanisms underlying cognitive biases and whether they are impacted in relation to ASD traits, in light of the increase in studies using the dot-probe paradigm with autistic individuals. Offshoots of the traditional methodology now include cognitive bias modification techniques, which are implemented to offset or ameliorate biased processing styles (see (Aday & Carlson, 2017). In these therapeutic sessions, using procedures similar to that of a dot-probe paradigm session, consistent and repeated exposure to circumstances in which the negative or threatening cue is repeatedly reinforced, or associated with positive outcomes, cognitive biases may be reduced or made to be more typical over time. Given the increasing prevalence of cognitive bias modification techniques, coupled with our still-stunted understanding of cognitive biases and how they should be measured across and within different vulnerable populations, it becomes increasingly important to identify key issues within the current methodology and ways they might be improved in the future. Further still, we do not fully understand how social stimuli, especially emotional faces, are processed or may be interpreted differently as a function of ASD traits. Although dot-probe paradigm and eye tracking methods are commonly used separately in cognitive tasks and they have been more recently combined, it appears that this combination in the absence of controlled eye movements is not an appropriate measurement of cognitive biases in neurotypicals, nor does it represent translatable methodology for individuals with more severe presentations of ASD traits.

The current work represents an important investigation of cognitive biases along a continuous distribution of ASD traits in a sample from the general population. We assessed the link between ASD traits and cognitive biases during an RT-based cognitive task with concurrent eye tracking. We found spurious relationships which failed to support the relationship between ASD traits and cognitive biases, and have provided evidence that cognitive biases should be further examined as a potential explanatory factor underlying some of the heterogeneity seen in ASD. Further, the manner in which emotional face processing is impacted as a function of ASD traits and how we structure tasks with emotional faces as stimuli should be assessed to develop appropriate measures of cognitive biases for individuals of wider cognitive, social, and verbal abilities. More complex investigation of these variables is warranted especially in light of the fact our sample made very few eye movements to the faces during the dot-probe paradigm in general.

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Appendix A – Letter of Information

Western

Sensory Processing in development and in autism Information letter – Adult

Prof. Ryan Stevenson Department of Psychology Western University [redacted]

1. **Invitation to participate**

You're invited to participate in a study investigating how sensory processing influences how we interact with the world, how that changes as you grow up, and where there are differences in individuals with autism. There will be two groups of participants recruited, individuals with and without autism spectrum disorder, with 800 individuals recruited in total, ranging in age from 4 to 65.

2. **Purpose of the Study**

The purpose of the study is to understand how people use the things they hear and see, how they put what they hear and see together, and how these processes develop to impact how people interact with the world, particularly those with autism. Almost everything people do in the world depends on how we perceive the world. Little is known about difference in how each one of us as individuals see, hear, and feel the world around us impact our communicative abilities, social abilities, and personalities. This study seeks to explore these relationships. This project is for research only, there is no clinical therapy element involved.

3. **How long will you be in the study?**

The study will take from 1-4 hours, depending on which portion of the experiment you are participating in today. Behavioural, eye tracking, EEG, fMRI, and questionnaire portions will last no longer that 2 hours

to complete. If you would like to complete multiple portions of the experiment, you can. Each portion will be described individually below.

4. **What are the study procedures?** All Participants

In order to participate, individuals must: a) normal or corrected-to-normal hearing and vision; and b) no known neurological issues (epilepsy, brain injury, etc.). If you have an ASD diagnosis, we will also ask you to bring verification of diagnosis, and participant in a diagnostic verification task.

This study will take place at four possible locations on the campus of the University of Western Ontario:

1. Westminster Hall
2. Natural Sciences Centre
3. Western Interdisciplinary Research Building
4. Robarts Research Institute

Questionnaires:

You may be asked to complete several questionnaires about a range of personal skills and characteristics on paper or computer-based forms, and will be asked to complete a problem solving task and vocabulary test. This portion of participation may last up to two hours. Participation will take place at Western Universities London campus or online.

Behavioural:

You will be asked to look at pictures, listen to sounds, feel gentle taps, and watch some short videos that have been created specifically to understand how people attend to and understand what they see and what they hear. During the session, your eye movements will be recorded and tracked using eye-tracking equipment.

EEG:

If you are volunteering to participated in an EEG session, you will be asked to wear a soft, damp net over your head while you attend to the presentations that will allow us to non-invasively record your brain’s activity. We will ask you to not wear makeup to an EEG session, and hair products (i.e. a hair dryer, shampoo, towels) will be provided following the EEG. This portion of participation may last up to two hours.

fMRI:

If you are volunteering to participated in an fMRI session, in order to participate, you will be screened for exclusionary criteria of the MRI itself, including:

1) Age outside of 4-65 years old
2) Weight more than 300 pounds due to scanner table limitations.
3) Significant medical illness (for example, cancer, HIV) or neurological illness (stroke, brain tumor, multiple sclerosis, epilepsy)
4) Active substance abuse or dependence in the last 3 months, excluding caffeine and nicotine
5) Head injury that has resulted in loss of consciousness for over 30 minutes
6) Pregnancy/possibility of pregnancy
7) Presence of any metal implant or shrapnel in the body
8) Claustrophobia
9) Breathing problems or motion disorders
8) Body piercing/tattoos
9) Permanent makeup
10) Dentures
11) Radiation seeds/implants
12) Pacemakers or implantable stimulation systems

Because the scanner environment is very unusual and potentially uncomfortable you will have the choice to first participate in a training program designed to familiarize you with the MRI scanning machine. In this case, participation will involve coming to Western on two occasions. On the first visit, you would practice participating in the MRI experiment in a special training facility and complete standardized tests. This includes lying on a “mock scanner” bed with a replica head coil, and being placed into an MRI scanner. You will be able to hear the noises the scanner will make, and experience what it will be like to be in the scanner. On the second visit, you will participate in the actual imaging procedure. If you are comfortable participating in the actual MRI on the first visit, that is also possible. The MRI training facility is located in room 221 of the Westminster Hall, which is located at 361 Windermere Rd. (near the corner of Windermere Rd. and Richmond St.). The actual MRI scanner is located in the Robarts Research Institute right beside the London Health Sciences Centre – University Campus on Perth Drive, just off Windermere Road in London Ontario. Magnetic resonance imaging is a non-invasive technique that does not involve injections, x- rays, or radiation.

5. **What are the risks and harms of participating?**

All studies, including this study, pose the possibility of confidentiality risks. These risks will be minimized in every way possible, detailed in section 8 of this document.

fMRI only: There are no known biological risks associated with MR imaging. Some people cannot have an MRI because they have some type of metal in their body. For instance, if you have a heart pacemaker, artificial heart valves, metal implants such as metal ear implants, bullet pieces, chemotherapy or insulin pumps or any other metal such as metal clips or rings, they cannot have an MRI. During this test, you will lie in a small closed area inside a large magnetic tube. Some people may get scared or anxious in small places (claustrophobic). An MRI may also cause possible anxiety for people due to the loud banging made by the machine and the confined space of the testing area. You will be given either ear plugs or specially designed headphones to help reduce the noise.

6. **What are the benefits of participating in this study?**

You may not directly benefit from participating in this study but information gathered may provide benefits to society as a whole which include understanding the role that sensory perception plays in typical development, which may lead to theories and practices to help individuals who exhibit impaired sensory perception, such as those with autism.

7. **Can participants choose to leave the study?**

Participation is completely voluntary, *you can withdraw from the study at any time*. If you decide to stop participating, you will still be eligible to receive the promised compensation for agreeing to be in this project. In the event you withdraw from the study, all associated data collected will be immediately destroyed wherever possible.

8. **How will participants' information be kept confidential?**

ALL INFORMATION OBTAINED DURING THE STUDY WILL BE HELD IN STRICT CONFIDENCE TO THE FULLEST EXTENT POSSIBLE BY LAW. WHILE WE DO OUR BEST TO PROTECT YOUR INFORMATION THERE IS NO GUARANTEE THAT WE WILL BE ABLE TO DO SO. THE INCLUSION OF YOUR NAME, CONTACT INFORMATION, AND DATE OF BIRTH MAY ALLOW SOMEONE TO LINK THE DATA AND IDENTIFY YOU. TO

MITIGATE THIS RISK TO THE GREATEST EXTENT POSSIBLE, ALL DATA WILL BE DE-IDENTIFIED IMMEDIATELY FOLLOWING COLLECTION AND LABELLED WITH A PARTICIPANT ID, AND THE FILE LINKING YOUR IDENTIFYING INFORMATION AND PARTICIPANT ID WILL BE KEPT UNDER LOCK AND KEY. ONLY STUDY TEAM WILL HAVE ACCESS TO STUDY- RELATED INFORMATION, AND REPRESENTATIVES OF THE WESTERN UNIVERSITY HEALTH SCIENCES RESEARCH ETHICS BOARD MAY REQUIRE ACCESS TO YOUR STUDY-RELATED RECORDS TO MONITOR THE CONDUCT OF THE RESEARCH. THE EXPERIMENTAL DATA ACQUIRED IN THIS STUDY MAY, IN AN ANONYMIZED FORM THAT CANNOT BE CONNECTED TO YOU, BE USED FOR TEACHING PURPOSES, BE PRESENTED AT MEETINGS, PUBLISHED, SHARED WITH OTHER SCIENTIFIC RESEARCHERS OR USED IN FUTURE STUDIES. YOUR NAME OR OTHER IDENTIFYING INFORMATION WILL NOT BE USED IN ANY PUBLICATION OR TEACHING MATERIALS WITHOUT YOUR SPECIFIC PERMISSION. STUDY MATERIALS WILL BE ARCHIVED FOR 5 YEARS FOLLOWING THE COMPLETION OF THE STUDY, ANALYSIS, AND PUBLICATION.

9. **Are participants compensated to be in this study?**

Yes. Participants from the SONA system will be compensated with 1 research credit per hour toward PSYC1000 for participating in this study. If you are enrolled in a course other than Psych 1000, your compensation will be based on your course outline. If you have any questions about the time or compensation, please feel free to contact the investigators before you consider signing the consent. Otherwise, compensation will be $5.00 for every 30 minutes of participation, and if travelling from outside of London, travel expenses will be reimbursed..

10. **What are the Rights of Participants?**

Your participation in this study is voluntary. You may decide not to be in this study. Even if you consent to participate you have the right to not answer individual questions or to withdraw from the study at any time. If you choose not to participate or to leave the study at any time it will have no effect on your academic standing if you are a student.

We will give you new information that is learned during the study that might affect your decision to stay in the study.

You do not waive any legal right by signing this consent form.

11. **Whom do participants contact for questions?**
If you have questions about this research study please contact: Prof. Ryan Stevenson at the Department of

Psychology, Western University, [redacted]

If you have any questions about your rights as a research participant or the conduct of this study, you may contact The Office of Research Ethics [redacted]

Thank you for your interest and participation in this study, it is greatly appreciated!

This letter is yours to keep for future reference.

Appendix B – Informed Consent Form

Sensory Processing in development and in autism

INFORMED CONSENT FORM

Prof. Ryan Stevenson Department of Psychology Western University [redacted]

I have read the Letter of Information, have had the nature of the study explained to me and I agree to participate. All questions have been answered to my satisfaction.

Questionnaires: Behavioural: EEG:
fMRI:

Name (please print): Signature:
Date:

☐ Yes ☐ Yes ☐ Yes ☐ Yes

☐ No ☐ No ☐ No ☐ No

____

____

____

Name of Person Obtaining Consent_________________________________ Signature of Person Obtaining Consent______________________________

Date for Person Obtaining Consent_________________________________

Appendix C – The Adult Autism-Spectrum Quotient

The Adult AQ

Participant # _______ **Sex** ___________________ **Handedness** _________________

Age ______________ **Date of birth** ____________ **Today's Date** _________________

Instructions: *Below are a list of statements. Please read each statement* *very carefully* *and rate how strongly you agree or disagree with it by circling your answer.*

DO NOT SKIP ANY STATEMENT.

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	definitely agree	slightly agree	slightly disagree	definitely disagree

look like.	
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

Appendix D – Ethics Approval

Western Research

Date: 7 June 2018

To: Prof. Ryan Stevenson

Project ID: 109024

Study Title: Sensory Processing in development and in autism

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

REB Meeting Date: June 19, 2018

Date Approval Issued: 07/Jun/2018

REB Approval Expiry Date: 07/Jun/2019

Dear Prof. Ryan Stevenson,

The Western University Research Ethics Board has reviewed the application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

Western University REB operates in compliance with, and is constituted in accordance with, the requirements of the TriCouncil Policy Statement: Ethical Conduct for Research Involving Humans (TCPS 2); the International Conference on Harmonisation Good Clinical Practice Consolidated Guideline (ICH GCP); Part C, Division 5 of the Food and Drug Regulations; Part 4 of the Natural Health Products Regulations; Part 3 of the Medical Devices Regulations and the provisions of the Ontario Personal Health Information Protection Act (PHIPA 2004) and its applicable regulations. The REB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000940.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Daniel Wyzynski, Research Ethics Coordinator, on behalf of Dr. Joseph Gilbert, HSREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Western Research

Date: 4 November 2019

To: Prof. Ryan Stevenson

Project ID: 108105

Study Title: Linking sensory perception and communication, social competency, and personality traits

Application Type: NMREB Amendment Form

Review Type: Delegated

Full Board Reporting Date: December 6 2019

Date Approval Issued: 04/Nov/2019

REB Approval Expiry Date: 27/Jun/2020

Dear Prof. Ryan Stevenson,

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed and approved the WREM application form for the amendment, as of the date noted above.

Documents Approved:

Document Name	Document Type	Document Date	Document Version
Assent Letter - Children - Clean	Written Consent/Assent	17/Oct/2019	1
Camp Letter	Recruiting Advertisements	29/Oct/2019	1
Consent Letter - Adult - Cleaned	Written Consent/Assent	17/Oct/2019	1
Consent Letter - Child - Cleaned	Written Consent/Assent	17/Oct/2019	1
Protocol - 108105 - cleaned	Protocol	29/Oct/2019	1
Recruitment Flyer - Camp	Recruiting Advertisements	29/Oct/2019	1
Recruitment Flyer - General	Recruiting Advertisements	29/Oct/2019	1

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

Kelly Patterson, Research Ethics Officer on behalf of Dr. Randal Graham, NMREB Chair

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

Meara Kathleen Stow
The University of Western Ontario
Department of Psychology

Education

2018-present Master of Science, Cognitive and Developmental Brain Sciences graduate degree, Brain and Mind Institute, University of Western Ontario, Canada.
Thesis title: *Autistic traits and cognitive biases for emotional faces in neurotypicals.* (to be completed 2020)

2013-2017 B.A. (Hons) in Psychology, University of Western Ontario, Canada.
Thesis title: *Inhibition mediated by neophobia in magpies and scrub-jays.*

Honours and Awards

SSHRC-Doctoral	$80,000
SSHRC-Master	$17,500
Autism Scholar's Award	$18,000
Graduate Research Awards	$925

Dean's List Honour Roll Recipient, University of Manitoba (2013-2017)

Papers in Peer-Reviewed Journals

2. Clary, D., **Stow, M. K**., Vernouillet, A., Kelly, D. M. (2019). Mirror-mediated responses of California scrub jays (Aphelocoma californica) during a caching task and the mark test. *Ethology*, 126, 1400-152. https://doi.org/10.1111/eth.12954
1. **Stow, M. K**., Vernouillet, A., & Kelly, D. M. (2018). Neophobia does not account for motoric self-regulation performance as measured during the detour-reaching cylinder task. *Animal Cognition*, 21(4), 565-574. doi:10.1007/s10071-018-1189-8

Supervisory and Presentation History

Papers in peer-reviewed journals (N = 2)
First-author conference presentations (N = 4)
Invited presentations (N = 1)
Student supervision undergraduate bachelor thesis (N = 1), University of Western Ontario.
Student co-supervision undergraduate bachelor thesis (N = 4), University of Manitoba.

Conference Presentations

8. **Stow, M. K.**, Sakellis, C., Handy, S., Garabedian, M., Tse Wing, W., Brierley, N., Altoum, E., Gateman, L., Stevenson, R. (2019). An Integrated Eye-Tracking Approach to the Study of Autism and Attentional Bias to Threat. Poster at the 2019 International Society for Autism Research, Montreal, Quebec.

7. **Stow, M. K.**, Sakellis, C., Handy, S., Garabedian, M., Tse Wing, W., Brierley, N., Altoum, E., Gateman, L., Stevenson, R. (2019). The Allocation of Cognitive Resources to Threat: Results of a Visual Detection Task. Poster at the 48th Annual Lake Ontario Visionary Establishment (LOVE) Conference, Niagara Falls, Ontario.

6. Hawkins, A., Schulz, S., **Stow, M.,** Shafai, F., Brierley, N., Altoum, E., Gateman, L., Garabedian, M., Abraham, A., Tse Wing, W., Parks, K., Stevenson, R. (2019). Hypersensitivity and Autistic Traits in Undergraduate Students. Poster at the 48th Annual Lake Ontario Visionary Establishment (LOVE) Conference, Niagara Falls, Ontario.

5. Shafai, F., Gateman, L., Abraham, A., **Stow, M. K.,** Sakellis, C., Altoum, E., Handy, S., Hawkins, A., Schulz, S., Tse Wing, W., Stevenson, R. (2019). The relationship between emotion recognition ability and traits associated with ASD: a pupillometric approach. Poster at the 2019 International Society for Autism Research, Montreal, Quebec.

4. Shafai, F., Gateman, L., Abraham, A., **Stow, M. K.,** Sakellis, C., Altoum, E., Handy, S., Hawkins, A., Schulz, S., Tse Wing, W., Stevenson, R. (2019). Anxiety Traits and Emotion Recognition: Insights from a Pupillometric Study. Poster at the 48th Annual Lake Ontario Visionary Establishment (LOVE) Conference, Niagara Falls, Ontario.

3. Iverson, D., **Stow, M. K.,** Kelly, D. M. (2018). Spatial Working Memory in Young and Aged Pigeons. Poster at the Undergraduate Research Symposium, University of Manitoba, Canada.

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1. **Stow, M. K**., Vernouillet, A., Kelly, D.M. (2017). Inhibition Mediated by Neophobia in Magpies and Scrub-Jays. Oral presentation at the Undergraduate Research Symposium, University of Manitoba, Canada.

Academic Positions

2018-2020 UWO (Department of Psychology) Graduate Teaching Assistant for 3800E “Psychological Statistics Using Computers”