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Autism, Alexithymia, and Anxious Apprehension: A Multimethod Investigation of Eye Fixation

Kevin G. Stephenson
Brigham Young University

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Kevin G. Stephenson

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Mikle South, Chair
Steven G. Luke
Michael J. Larson
Rebecca A. Lundwall
Jared S. Warren

Department of Psychology

Brigham Young University

ABSTRACT

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Kevin G. Stephenson
Department of Psychology, BYU
Doctor of Philosophy

Reduced eye fixation and deficits in emotion identification accuracy have been commonly reported in individuals with autism spectrum disorder (AS), but are not ubiquitous. There is growing evidence that emotion processing deficits may be better accounted for by comorbid alexithymia (i.e., difficulty understanding and describing one's emotional state), rather than AS symptoms *per se*. Another possible explanation is anxiety, which is often comorbid with AS; emotion processing difficulties, including attentional biases, have also been observed in anxiety disorders, suggesting that anxiety symptoms may also influence emotion processing within AS. The purpose of the current study was to test the role of dimensional symptoms of autism, anxious apprehension (AA), and alexithymia in mediating eye fixation across two different facial processing tasks with three adult samples: adults diagnosed with autism (AS; $n = 30$), adults with clinically-elevated anxiety without autism (HI-ANX; $n = 29$), and neurotypical adults without high anxiety (NT; $n = 46$). Experiment 1 involved participants completing an emotion identification task involving short video clips. Experiment 2 was a luminescence change detection task with an emotional-expression photo paired with a neutral-expression photo. *Joy, anger,* and *fear* video and photo stimuli were used. Dimensional, mixed-effects models showed that symptoms of autism, but not alexithymia, predicted lower eye fixation across two separate face processing tasks. There were no group differences or significant dimensional effects for accuracy. Anxious apprehension was negatively related to response time in Experiment 1 and positively related to eye fixation in Experiment 2. An attentional avoidance of negative emotions was observed in the NT and HI-ANX group, but not the AS group. The bias was most pronounced at *lower* levels of AS symptoms and *higher* levels of AA symptoms. The results provide some evidence for a possible anxiety-related subtype in AS, with participants endorsing high autism symptoms, but low anxious apprehension, demonstrating more classic emotion processing deficits of reduced eye fixation.

Keywords: alexithymia, anxious apprehension, autism, emotion, eye fixation, eye tracking, mixed-effects modeling

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Autism spectrum disorder (AS) consists of a wide-ranging constellation of symptoms that include deficits in social communication and social interaction as well as patterns of restricted and repetitive behaviors or interests (American Psychiatric Association, 2013). As specified in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5; American Psychiatric Association, 2013), there are a number of deficits in social communication and social interaction in individuals with AS. Social communicative deficits include impairments in nonverbal social communication such as abnormal eye contact and difficulty understanding gestures and facial expressions. There are also deficits in reciprocity including difficulties maintaining back-and-forth communications as well as limited interest in others' emotions and interests. Lastly, individuals with AS show impairments with interpersonal relationships including such as establishing, maintaining, and understanding typical social relationships.

These core symptoms of AS are associated with significant functional impact and distress in those individuals directly affected in addition to reduced quality of life for caregivers and family members (Clark, Magill-Evans, & Koning, 2015; Emily & Grace, 2015; Persson, 2000; Renty & Roeyers, 2006). Parents seem to be concerned with additional associated features of AS, likely caused at least in part by the core social deficits, such as school difficulties, bullying, and stress experienced by their children with AS (Lee, Harrington, Louie, & Newschaffer, 2008). Furthermore, decreased family quality of life, including quality of family interactions, physical and financial well-being, emotional well-being, and level of support is positively correlated with increasing levels of adaptive functional impairment, particularly daily living skills, even after controlling for socio-economic status and behavior-problem concerns (Emily & Grace, 2015).

There is also increased anxiety within AS (Kerns & Kendall, 2012; Kerns & Kendall, 2014; Kim, Szatmari, Bryson, Streiner, & Wilson, 2000; Sukhodolsky et al., 2008; White, Oswald, Ollendick, & Scahill, 2009). Anxiety symptoms, as well as those of AS, are predictive of lower quality of life (van Steensel, Bögels, & Dirksen, 2012). In fact, van Steensel et al. (2012) found that parents of children with AS rated their children higher in symptoms of social anxiety, specific phobia, and panic symptoms compared to parents of children with anxiety disorder. Although no group differences were found in reported quality of life, autism and anxiety scores were negatively correlated with quality of life. These findings highlight the need to better understand the underlying processes of social and emotional deficits and struggles in AS in order to intervene in these specific difficulty areas and improve overall quality of life for both individuals with AS as well as their families.

Emotion Processing and Autism

Atypical emotion processing is one major line of research as a possible mechanism of social deficits observed in AS. The results of a recent meta-analysis (Lozier, Vanmeter, & Marsh, 2014) indicate that the majority of studies suggest that individuals with AS, from early childhood through adulthood, have impaired accuracy when labeling emotional faces with an overall mean accuracy difference of 11.91 percent (SD = 61.01). Lozier et al. (2014) also reported that the labeling deficits worsen with age with young children with AS having an average of 6.82 percent difference in emotion identification while adults having an average accuracy difference of 15.85 percent. These emotion labelling deficits remained significant even after controlling for full-scale IQ scores. However, the authors reported a marginally significant Age × FSIQ interaction suggesting that the age-related deficits were worse in participants with lower FSIQ. They also found emotion-specific differences with *anger*, *fear*, and *surprise*

emotions having the largest differences in AS compared to controls and *happiness* showing the least amount of difference. This is not surprising given that accuracy rates for *happiness* in studies included in this meta-analysis showed relatively high accuracy among both AS and control groups with mean accuracy scores above 95% for both groups, whereas mean accuracy for other emotions ranged from 53% to 78%. This suggests that individuals are especially proficient at identifying *happiness,* and a ceiling effect may exist for this emotion, thereby limiting the amount of variability and limiting the chances of finding significant group differences. Yet, this is not to say that the findings are unanimous in emotion processing outcomes. Some studies show atypical face processing while others do not show such differences or show differences in different domains such as in eye-tracking patterns, event-related potentials, or emotional neurocircuitry activation (see Harms, Martin, & Wallace, 2010; Lozier et al., 2014; Nuske, Vivanti, & Dissanayake, 2013). Despite the general trend of impaired emotion identification, there are interesting nuanced differences in various areas when investigating emotion identification amid differences in response times as well as differences in accuracy between emotions.

Some researchers have used both accuracy and response times when participants label emotions as measures of potential emotional processing impairment in AS. Dalton and colleagues (2005) showed increased response time with a group of 14 adolescent/young adult males with AS, compared to controls, when rating emotional (but not neutral) faces and when those faces were facing directly forward (but not when quarter-turned). The AS group also had significantly reduced emotion identification accuracy. Another study also found both reduced emotion identification accuracy as well as increased accuracy-adjusted response time in a large sample of adults with AS (n = 314, 150 female) compared to controls (n = 184, 92 female;

Sucksmith, Allison, Baron-Cohen, Chakrabarti, & Hoekstra, 2013). Within a sample of typically-developing college students, individuals scoring high on the Autism Quotient (AQ) had increased response time on an emotion identification flanker task compared to individuals who scored low on the AQ (Dickter, Burk, Fleckenstein, & Kozikowski, 2018).

These studies provide evidence of increased emotion identification response times at higher levels of AS symptoms alongside concurrent emotion identification difficulties. This co-occurrence of emotion identification and response time differences in AS, compared to typically-developing comparison groups, may suggest potential causal relationships between these two variables (either direction) or a shared etiology. In terms of differences in emotion identification accuracy between different emotions, there is a trend for more significant differences in the emotions of *anger*, *fear*, and *surprise* with less conclusive evidence for impairments in recognizing *happiness*, *sadness*, and *disgust* (Lozier et al., 2014). Although Lozier et al. (2014) did not provide a rationale or reasoning behind these emotion-specific differences, others have suggested that the observed difficulties with negative emotions provides evidence for the "amygdala theory of autism" proposed by Baron-Cohen and colleagues (Ashwin, Chapman, Colle, & Baron-Cohen, 2006; Baron-Cohen et al., 2000; Uljarevic & Hamilton, 2013). This theory posits that abnormal amygdala function may be a central contributor to social-emotional deficits in autism given its role in social processing and activation during processing of negative emotions.

There are other possible sources of observed difficulties in emotional labeling and response time within AS. There has been considerable work investigating possible neural mechanisms of poor emotion identification. However, there is heterogeneity in the findings with some showing significant reductions in fusiform gyrus activity relative to controls, typically

thought to be involved in processing of faces (Corbett et al., 2009), while others have found no differences in that region (Kleinhans et al., 2011). Other implicated areas of poor emotion processing in AS compared to typically-developing individuals include amygdala (Corbett et al., 2009; Kleinhans et al., 2009, 2011) and superior temporal sulcus (Alaerts et al., 2014; see review by Nomi & Uddin, 2015). However, there continue to be many lingering questions as to differences in neural developmental trajectories between individuals with different severities (Courchesne et al., 2007; Courchesne, Campbell, & Solso, 2011; Minshew & Williams, 2007). In addition to structural anatomical explanations provided by neuroimaging, other methods, such as eye tracking, can provide insight into the development of reduced emotion identification accuracy in AS.

Another potential explanation for generally reduced emotion identification accuracy is the observed tendency for individuals with AS to spend less time looking into people's eyes (Papagiannopoulou, Chitty, Hermens, Hickie, & Lagopoulos, 2014). Early eye-tracking studies showed reduced face, and particularly eye, fixation in older adolescents and adults (Kliemann, Dziobek, Hatri, Steimke, & Heekeren, 2010; Klin, Jones, Schultz, Volkmar, & Cohen, 2002; Pelphrey et al., 2002). This has since been studied more extensively in child AS samples, where reduced fixation to the eyes is also a frequent finding (see Papagiannopoulou et al., 2014 for a review). Abnormalities in eye fixation have been observed in individuals as young as 2-6 months (Jones & Klin, 2013). Toddlers with AS may also show more of a preference to geometric shapes compared to social images (Pierce et al., 2016). Evidence also suggests that abnormal eye processing continues into adulthood (Kirchner, Hatri, Heekeren, & Dziobek, 2011; Yi et al., 2014) although other evidence suggests that this may not be the case (Cook, Brewer, Shah, & Bird, 2014). Tanaka and Sung (2016) have attempted to connect the disrupted face

processing network hypothesis with the reduced eye fixation hypothesis by proposing the "eye avoidance hypothesis" which posits that individuals with AS have an increased fear response, evidenced by amygdala hyperactivity, when looking into people's eyes; because of this, reduced eye fixation is viewed as an early coping strategy to modulate the atypically increased fear response when individuals with AS engage in direct eye contact.

In sum, the body of existing research leans towards the notion of atypical emotional processing in individuals with AS, particularly for the evaluation of emotional faces. However, the results are not consistent which has caused some to investigate more parsimonious explanations for the discrepant findings in abnormal visual face processing and reduced emotion identification accuracy among some individuals with AS compared to typically-developing individuals.

Alexithymia and Autism

One potential contributor to emotion processing deficits in AS is the construct of alexithymia. Alexithymia, coined by Sifneos (1973), is a condition characterized by difficulties identifying and describing one's own emotional state. Alexithymia prevalence has been reported to be between 40% and 65% in AS (Berthoz & Hill, 2005; Hill, Berthoz, & Frith, 2004), whereas the typically-developing population has a prevalence of approximately 10%-13% (Salminen, Saarijärvi, Äärelä, Toikka, & Kauhanen, 1999; Taylor, Bagby, & Parker, 1997). Alexithymia is also reported to be elevated in a number of other psychiatric and medical conditions including eating disorders (Cochrane, Brewerton, Wilson, & Hodges, 1993), depression (Kim et al., 2008), anxiety disorders (Cox, Swinson, Shulman, & Bourdeau, 1995; De Berardis et al., 2008), traumatic brain injury (Williams & Wood, 2010), and somatoform disorders (Taylor et al., 1997).

The developmental mechanisms of alexithymia are not well understood. However, there are a number of proposed developmental associations. For example, early language deficits have been linked to future alexithymic traits as have irregularities in the autonomic nervous system and the immune system (see Karukivi & Saarijärvi, 2014 for a review). Alexithymia has also been associated with a number of genetic, neurobiological, and environmental factors (Karukivi & Saarijärvi, 2014). Yet, there is a gross lack of studies directly investigating the causal relationship between alexithymia and associated characteristics. Additionally, conducting studies is complicated by the difficulty in identifying alexithymic traits prior to late adolescence (Loas, Braun, Delhaye, & Linkowski, 2017). Despite the lack of evidence regarding causal relationships of alexithymia, there are, however, studies that provide insight into this research question.

In trying to better understand the phenomenon of alexithymia, researchers have investigated possible subtypes. Vorst and Bermond (2001) identified two possible types of alexithymia, type I being defined as low awareness of physiological arousal and process of emotion (with a low degree accompanying emotional cognitions), and type II being defined as normal or high awareness of physiological emotional response also paired with a low degree of accompanying emotional cognitions. Research suggests that individuals with AS may struggle most with the type II (or cognitive) alexithymia (Berthoz & Hill, 2005). However, other researchers have questioned the validity of these subtypes as the two subtypes of alexithymia did not have empirical support from a large (n = 1696) confirmatory factor analysis (Bagby et al., 2009). Among other proposed subtypes includes a possible "organic alexithymia" associated with acquired brain injury (Becerra, Amos, & Jongenelis, 2002). While others have found evidence for a more mild emotional "anomia" type of alexithymia along with a more severe

"agnosia" of emotion which consists of deficits in actual mental representation of emotion (Lane, Hsu, Locke, Ritenbaugh, & Stonnington, 2015). In other words, some individuals may have a basic understanding of what emotions are and feel like, but simply cannot access the appropriate word for it, while others may fail to grasp the actual concept of what an emotion is. Despite these interesting potential subtypes within alexithymia, the majority of research has focused on a more cognitive presentation of alexithymia (Bagby, Parker, & Taylor, 1994).

The investigation of alexithymia in AS has also primarily focused on the cognitive alexithymia presentation. There is a growing body of research in support of the so-called "alexithymia hypothesis" in AS (Bird & Cook, 2013; Bird et al., 2010; Bird, Press, & Richardson, 2011; Cook, Brewer, Shah, & Bird, 2013), stating that deficits in emotional processing seen in AS may be better explained by higher rates of comorbid (cognitive) alexithymia rather than by autism symptoms *per se*. Cook and colleagues (2013) showed that alexithymia, but not autism symptoms, predicted reduced emotional facial recognition. Their sample included a group of individuals with AS *(n* = 16) and a typically-developing control group (*n* = 16) that was matched on levels of alexithymia. Their research paradigm included two tasks involving labeling emotions portrayed in faces as well as a task requiring participants to simply identify differences in morphed facial stimuli, without commenting on the emotion being portrayed. While alexithymia was correlated with the emotional task, it was not related to the physical difference identification task suggesting that alexithymia is uniquely involved in emotional processing of faces rather than overall facial processing in general. This study provides evidence that a lack of awareness of one's own emotions may lead to difficulties identifying emotions in others. However, it should be noted that the opposite may be true; in other words, deficits in identifying emotions in others may cause deficits in understanding

internal emotional states. A better understanding of the development of alexithymia will be needed before this question can be adequately addressed.

Another study from the Bird research group investigated the role of alexithymia in eye fixation in a sample of 26 adults, 13 with AS (Bird et al., 2011). Participant eye movements were monitored while they viewed two video clips of people engaging in an emotional conversation (from the television drama "Damages") as well as two videos clips of newscasters giving news reports. The control group, but not the AS group, showed a preference for face vs. nonface areas. The AS group had reduced overall eye fixation, compared to the control group, but did not significantly differ in the eye:mouth ratio when fixating the face. Using stepwise regression with the AS group alone, the authors used scores on the Autism Diagnostic Interview Schedule (ADOS) and the Toronto Alexithymia Scale-20 (TAS) as predictors. They found that social attention (i.e., face:nonface proportion) was predicted by autism symptoms (ADOS) whereas attention within the face (i.e., eye:mouth proportion) was predicted by alexithymia symptoms (TAS), offering additional evidence for the contribution of alexithymia to face processing in AS. However, it should be noted that they did not test for the influence of these predictors using dimensional symptoms in control groups since the use of ADOS scores precluded the inclusion of the control group in determining the impact of both alexithymic and autistic traits on eye fixation.

In addition to being involved in processing of emotional faces, alexithymia also seems to contribute to the processing of non-facial emotional stimuli such as music. Allen, Davis, and Hill (2013) had participants listen to emotionally-charged music while monitoring physiological responses. After listening to the music, the participants were asked to match the music with emotional words that they felt best described the passage. While they found no group

differences in overall physiological responsiveness to music, individuals with AS were significantly impaired in their verbal processing of emotional music. However, this difference was no longer significant after controlling for alexithymia.

Alexithymia has also been implicated in other social cognitive processes such as empathy (Bird et al., 2010) and social reward (Foulkes, Bird, Gökçen, McCrory, & Viding, 2015). There is evidence that alexithymia modulates insular brain activation during an "empathy for pain" paradigm in AS (Bird et al., 2010). Additionally, the differences in empathy between individuals with AS and typically-developing individuals was no longer significant after controlling for alexithymia. Other research has also suggested hypoactivity in insular regions among individuals with AS while engaged in emotional introspection when viewing emotionally-salient images (Silani et al., 2008). As expected, this decreased insular response in AS compared to controls was related to both increased alexithymia and decreased empathy scores.

Similar to introspection, interoception involves sensing and being aware of internal processes, but it is focused more specifically on physiological sensations such as heart rate. Interoception has been found to be atypical in AS (Garfinkel et al., 2016; Quattrocki & Friston, 2014) and may be of clinical relevance and concern (Bird & Cook, 2013). Garfinkel et al. (2016) found that individuals with AS rated their own subjective interoceptive sensitivity to be high, while their actual interoceptive accuracy was low. This discrepancy was associated with increased levels of anxiety and the authors concluded that this provides evidence that this prediction error may actually be linked to the pathogenesis of anxiety. Interestingly, alexithymia also accounts for deficits in interoception, measured by counting one's own heartbeats, yet autism symptoms do not (Shah, Hall, Catmur, & Bird, 2016). This relationship between alexithymia and interoception suggests that alexithymia may be involved in a broader range of

internal self-awareness processes apart from simply emotional self-awareness and has implications for increased rates of anxiety seen in AS populations (Kim et al., 2000; Sukhodolsky et al., 2008; White et al., 2009).

Taken together, alexithymia seems to play a role in many of the socio-emotional deficits that are core to AS including social cognitive processes, interoception, and monitoring of emotional states. However, alexithymia also is involved in associated features such as anxiety and emotion regulation problems. Because of this, alexithymia is not only a worthwhile covariate to include, but a necessary construct in any emotional processing study in AS.

Anxiety and the Nonspecificity of Emotional Processing Difficulties

Another possible explanation for reduced eye fixation in AS could be the presence of co-occurring anxiety. Meta-analytic estimates suggest that comorbid anxiety disorders are present in 39.6% of youth with AS, with prevalence rates across studies ranging from 7.5% to 75% (van Steensel, Bögels, & Perrin, 2011). Estimated prevalence rates in adults with AS range anywhere from 29% to 50% (Croen et al., 2015; Joshi et al., 2013; Lugnegård, Hallerbäck, & Gillberg, 2011). Prevalence for both children and adults is likely higher when accounting for "atypical" symptoms of anxiety in AS, or symptoms that do not align neatly with DSM definitions, but might pertain to anxiety surrounding autism symptoms (e.g., worries pertaining to intense interests, lack of fear of negative evalation, but intense social discomfort; see Kerns et al., 2014). This may include especially elevated anxious apprehension or ruminative worries (Kerns et al., 2014).

Anxiety within AS has been suspected of contributing to eye contact deficits. The "hyperarousal model" posits that individuals with AS have an abnormally adverse reaction to the face and eyes of others. According to this model, gaze avoidance could be an adaptive response

to mitigate the intense arousal, although the evidence for this model is still somewhat lacking (see Senju & Johnson, 2009 for a review). Reduced eye fixation in adults with Asperger's syndrome, as well as subsequent reductions in identification accuracy, have been associated with greater levels of social anxiety within the Asperger's syndrome group compared with typically-developing controls, matched for age and IQ (Corden, Chilvers, & Skuse, 2008). Furthermore, in a sample of women with high, medium, and low levels of social anxiety (but not AS), individuals who were highly socially anxious experienced greater physiological arousal (i.e., cardiac acceleration), compared to the other groups, when viewing direct gaze. However, they did not exhibit any differences in eye fixation. In fact, the highly anxious group tended to fixate the eyes *more* and not less than individuals in the other two groups (Wieser, Pauli, Alpers, & Mühlberger, 2009). These seemingly discrepant finding may be, in part, due to differential effects of anxiety within AS compared to the phenotype within classic anxiety disorders and suggests the need to directly compare both groups to better understand the role of anxiety and AS in social perception and processing.

Anxiety and alexithymia are associated with each other and also with autism symptoms in both AS and non-AS samples. A review of 24 behavioral and neuroimaging studies (Grynberg et al., 2012) showed that anxiety and depression are associated with higher rates of alexithymia and that alexithymia decreases emotional face decoding abilities. Anxious adults without AS have elevated scores on the SRS-2 self-report measure of autism symptoms (South, Carr, Stephenson, Maisel, & Cox, 2017). In a large (n = 151), multinational sample of adults with and without AS, Maisel et al. (2016) found that alexithymia significantly mediated the relationship between dimensional symptoms of autism and anxiety. Additionally, during a visual search task requiring participants to determine if several faces presented on a screen were the

same emotion or if one face differed from the others, typically-developing college students with high social anxiety showed reduced accuracy compared to those with low social anxiety. However, there were no differences in performance for individuals with high AQ scores compared to those with low AQ scores (Dickter et al., 2018). These overlaps highlight the need to consider both alexithymia and anxiety in the presence of emotional processing deficits within AS.

It is important to note that emotional impairments are not necessarily universal in nor unique to AS (Nuske et al., 2013). There exists a significant overlap between AS, anxiety, alexithymia, and emotion processing difficulties. Individuals with anxiety and depression have displayed reduced accuracy in identifying emotional faces (Demenescu, Kortekaas, Boer, & Aleman, 2010). There is also evidence of reduced eye-fixation in anxiety-related disorders, notably social anxiety disorder (Horley, Williams, Gonsalvez, & Gordon, 2003; Moukheiber et al., 2010). Alexithymia has explained emotion labeling difficulties in clinical conditions other than AS, such as eating disorders and somatoform disorders (see review by Grynberg et al., 2012). Studies with non-clinical samples have found associations between emotion identification accuracy and alexithymia with high-low split groups (Jessimer & Markham, 1997; Mann, Wise, Trinidad, & Kohanski, 1994; Montebarocci, Surcinelli, Rossi, & Baldaro, 2011), but not when analyzed dimensionally (Prkachin, Casey, & Prkachin, 2009).

In addition to abnormal eye fixation, individuals with anxiety have also shown other differences in eye-tracking patterns, compared to control groups, when viewing emotional faces by way of attentional biases for threatening stimuli (Armstrong & Olatunji, 2012). This provides evidence of the presence of face processing differences in anxiety without the presence of AS. However, children with AS and comorbid anxiety do not seem to show the same bias (Hollocks,

Ozsivadjian, Matthews, Howlin, & Simonoff, 2013; May, Cornish, & Rinehart, 2015), but there have not been studies investigating attentional biases in adults with AS and heightened anxiety without AS in the same study. Although anxiety is often discussed as a unitary construct, previous studies have shown differential patterns of brain activation for anxious apprehension (i.e., apprehensive worries) vs. anxious arousal (i.e., somatic anxiety, fear response) which suggests at least two separate constructs (Engels et al., 2007, 2010; Nitschke, Heller, Palmieri, & Miller, 1999). The construct of anxious apprehension may be especially relevant in AS given the high amounts of ruminative worry observed within AS (Kerns et al., 2014).

The Present Study

While the emotional processing literature suggests that the majority of studies find atypical performance among individuals with AS, there still exist a considerable amount of evidence for lack of difference between typically-developing comparison groups (Chita-Tegmark, 2016; Papagiannopoulou et al., 2014). To account for and explain the observed discrepancies in findings between studies, some have suggested possible subtypes of autism such as those with comorbid alexithymia or anxiety (e.g., Bird et al., 2011; White et al., 2014). Others have suggested differences in experimental design such as the use of explicit vs. implicit tasks involving the processing of emotion (Nuske et al., 2013). However, additional research is needed to better understand the relative contribution of these possible explanatory variables. Moreover, many of these constructs appear to be interrelated. Despite the significant overlaps between AS, alexithymia, and anxious apprehension, few studies to date have investigated these different characteristics at once. There are no known studies that have investigated the contributions of alexithymia on eye fixation during emotional facial processing within a transdiagnostic sample.

The purpose of the current study was to test the role of AS, anxious apprehension, and alexithymia symptoms in mediating eye fixation across two different facial processing tasks, with three transdiagnostic adult samples: adults diagnosed with autism (AS), adults with self-reported clinically-elevated anxiety but not autism (HI-ANX), and neurotypical adults without high anxiety (NT). We specifically investigated the emotions of *anger*, *fear*, and *happiness*. *Anger* and *fear* are the emotions that have the most consistent evidence of group differences in emotion processing within AS (Nuske et al., 2013), and *happiness* was chosen as a contrast for these negatively-valenced emotions. The first task was an explicit emotional identification task using short video clips. The second task was a luminescence change detection task that did not require explicit judgement of emotion. Eye fixation was the primary dependent variable across both studies. We used mixed-effects models to analyze the repeated-measure experimental design. These models have a number of advantages over more classical analysis of variance (ANOVA) methods including managing missing data (allowing the use of all available data) and properly accounting for correlation of multiple observations within participants (i.e., properly handling non-independence of observations) which increases statistical power. These advantages make them the preferred method over repeated measures ANOVA for analyzing repeated-measures designs (Gueorguieva & Krystal, 2004).

Our first aim was to replicate previously-reported findings of reduced eye fixation (Papagiannopoulou et al., 2014), increased response time, and reduced accuracy (Nuske et al., 2013) in the AS group compared to controls. We hypothesized that *fear* and *anger* would show the most robust results, compared to *happiness* (following Nuske et al., 2013). Based on previous research, we expected alexithymia symptoms, and not autism symptoms, would predict eye fixation and emotional identification accuracy among all participants (following Bird et al.,

2011; Cook et al., 2013). A secondary aim of this study was to evaluate the extent to which adults with AS and heightened anxious apprehension show a bias towards threatening stimuli. Based off the extant child research in this area, we hypothesized that the clinically anxious group would show a bias (i.e., increased face fixation) toward threatening stimuli, but those in the AS group will not (Armstrong & Olatunji, 2012; Hollocks et al., 2013; May et al., 2015).

Method

Participants

Participants were recruited as part of a larger study and consisted of three groups of adults (i.e., neurotypical adults, adults diagnosed with autism, and adults with high self-reported anxiety without autism). All participants had average or above average intelligence (> 85) as measured by the Wechsler Abbreviated Scale of Intelligence – Second Edition using the two-subtest form (WASI-2; Wechsler & Hsiao-pin, 2011). There were no significant differences between groups for IQ, $F(2, 89) = 0.01$, $p = .99$ (see Table 1).

Table 1

Participant Characteristics

	AS Mean (*SD*)	NT Mean (*SD*)	HI-ANX Mean (*SD*)	F	*p*	Difference
N	30	46	29	-	-	-
% Male*	82%	69%	38%	-	-	-
Age	24.52 (6.04)	20.93 (2.03)	21.58 (2.74)	7.67	< .001	AS > NT, ANX
FSIQ	112.36 (10.63)	111.95 (8.21)	112.16 (12.13)	0.01	.99	AS = NT = ANX
TAS	55.05 (11.47)	42.89 (9.46)	48.69(11.50)	9.75	< .001	AS > NT = ANX
AQ	28.38 (9.15)	15.84 (6.36)	23.38 (7.35)	23.03	< .001	AS > HI-ANX > NT
PSQ	50 (15.48)	46.09 (13.04)	62.85 (9)	14.64	< .001	HI-ANX > AS, NT

Note: AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group; FSIQ = Full Scale Intelligence Quotient; TAS = Toronto Alexithymia Scale – 20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; RT = response time (in milliseconds). *Significant differences according to Kruskal-Wallis test [$H(2) = 6.83$, $p = .03$].

The neurotypical group (NT; $n = 46$) consisted of university students with no reported history of psychiatric or neurological conditions recruited through an online research participation system and who received course credit for their participation. The AS group ($n = 30$) consisted of adults recruited from an existing database as well as through printed fliers and by word of mouth. Diagnosis was confirmed using the ADOS-2 (Lord et al., 2012) by a clinician with established research reliability. Due to the high prevalence of comorbidity within AS, participants with AS were not excluded for comorbid psychiatric disorders. A high-anxiety control group (HI-ANX; $n = 29$) was recruited from individuals presenting for psychotherapy at a counseling center of a large private university who had not yet begun, or only just begun psychotherapy; the specific number of sessions attended was not available. Formal diagnoses were not available for this group. They were screened using a routine intake questionnaire, the Counseling Center Assessment of Psychological Symptoms (CCAPS; Locke et al., 2011). The CCAPS is a widely-used screening questionnaire for psychological disorders that has strong psychometrics including a cross-validation of the proposed factor structure using confirmatory factor analysis, alpha coefficients for all subscales ranging from .78 to .91, moderately high correlations between subscales and related measures, and good test-retest reliability (.76-.93). It has eight subscales covering a number of psychological and distress symptoms. Individuals scoring above established cutoffs on at least one of the two anxiety subscales (Generalized Anxiety and Social Anxiety) as well as scoring below the 80th percentile for the Depression, Eating Concerns, and Substance Use subscales were invited to participate in the study. Additionally, individuals in the HI-ANX group did not have a reported history of AS. Participants in the HI-ANX and AS groups received $15/hr for their participation. All recruiting and experimental procedures were approved by the university's Institutional Review Board.

Measures

Autism symptoms. The Autism Quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) is a self-reported measure of autism symptoms. The AQ was not created as a diagnostic measure, but rather a dimensional measure of traits along the autism spectrum with psychometric support in both a general (i.e., non-AS) and AS population. The AQ consists of 50 questions using a 4-point Likert scale and separated into five domains: *social skill, attention switching, attention to detail, communication,* and *imagination*. Updated psychometrics are provided by Stevenson and Hart (2017). Test-retest reliability for the total score was $r = .86$ and internal consistent for the total score was $\alpha = .79$. Subscale internal consistency measures ranged from .46-.75.

Alexithymia. The Toronto Alexithymia Scale - 20 (TAS; Bagby et al., 1994) is one of the most widely used self-report measures of alexithymia. It consists of 20 questions on a 5-point Likert scale ranging from *Strongly Disagree* to *Strongly Agree*. The TAS-20 has three subscales including *Difficulty Identifying Feelings, Difficulty Describing Feelings,* and *Externally-Oriented Thinking*. Additionally, the TAS-20 has the following cutoff criteria: *Alexithymia* ($\geq$ 61), *Possible Alexithymia* (52 to 60), and *Non-Alexithymia* ($<$ 52). Confirmatory factor analysis of the 3-factor model revealed acceptable fit statistics (CFI = .97, RMSEA = .06). Internal consistency was also acceptable for the total score ($\alpha = .86$) and the three proposed factors ($\alpha = .70$ - .81).

Anxious apprehension. The Penn State Worry Questionnaire (PSQ; Meyer, Miller, Metzger, & Borkovec, 1990) is a measure of self-reported generalized worry or anxious apprehension (e.g., "I am always worrying about something"). It contains 16 questions using a 5-point Likert scale ranging from *Not at all typical of me* to *Very typical of me*. Psychometric

properties of the PSQ are acceptable. Test-retest reliability was acceptable at two ($r = .75$) and four ($r = .74$) weeks and internal consistency was high ($\alpha = .93$). Additionally, the PSQ shows adequate convergent and discriminant validity.

Stimuli

Dynamic face stimuli. Dynamic faces were selected from the Amsterdam Dynamic Facial Expression Set (ADFES; van der Schalk, Hawk, Fischer, & Doosje, 2011). The ADFES is a commonly-used, standardized database of videos of individuals depicting emotional expressions initiated from a neutral expression. The neutral expression is held for .5 s followed by the target emotion being held for 5 s. The total duration of all the clips range from 6 s to 6.5 s. The ADFES included 20 models aged 18-25 with an equal distribution of gender. Half of the models were of northern European heritage and half were Turkish and North-African models (referred to as Mediterranean models). However, to match the ethnicity of the static stimuli, only the North-European stimuli were used in the current study. The ADFES includes face-front and turn-away orientations, but only the face-front orientation stimuli were used. *Joy*, *angry*, and *fearful* stimuli were used for the present study (see Appendix A for a complete list of dynamic face stimuli used).

Static face stimuli. Static face images were selected from the Karolinska Directed Emotional Faces (KDEF; Goeleven, De Raedt, Leyman, & Verschuere, 2008) which is another commonly-used, standardized set of emotional faces containing depictions of basic emotions (*joy*, *angry*, and *fearful* stimuli were selected for the current study) as well as a neutral face expression. The complete KDEF stimuli included 70 Caucasian models (35 female). The models were amateur actors between 20 and 30 years of age who all wore grey t-shirts. They did

not have facial hair, earrings, glasses, or visible makeup. All the models in the KDEF were front-facing (see Appendix B for complete list of static face stimuli used).

Procedures

All participants came to the lab to participate in a larger battery of eye-tracking paradigms during a single visit (see Appendix C for a list of other tasks completed). Visits typically lasted two and a half hours. Upon arrival, participants reviewed and signed a consent form and a research assistant explained the research procedures. Next, participants completed an hour-long eye-tracking session (including the two tasks from the current study and one other task [see Appendix C]) which was followed by the WASI-2, the computer-administered questionnaires listed above, and then an additional 30-minute eye-tracking session (see Appendix C). Participants were encouraged to take breaks as needed throughout the experiment (between tasks). Administration of the ADOS-2 for participants in the AS group occurred prior to participating in the current study.

Eye-tracking. Eye movements were recorded using an SR Research Eyelink 1000 eye tracker which samples at a rate of 1000Hz and has a spatial resolution of 0.01˚. Head movements were minimized by a head and chin rest. Eye movements were recorded from the right eye, as is standard practice in the field. Calibration occurred prior to completing the experimental tasks using a 9-point calibration routine with maximum error less than 1˚ and participants were recalibrated after each block and as needed throughout the experiment (e.g., after moving during a break). The experiment was run using SR Research Experiment Builder software.

Facial regions. The stimuli were segmented in areas of interest including the eyes, mouth, face, and non-face. Separate masks were fitted to each individual model (emotions

combined) for both sets of stimuli, optimizing the accuracy of facial regions. The areas were sized to include the extreme points so as to include the entire region for each emotion per model. Eye interest areas were rectangular and included the area containing the eyebrows and was lower-bounded by the palpebromalar sulcus. Mouth interest areas were elliptical and were bounded by the nasal septum and the mentolabial sulcus. Face interest area regions were also elliptical and were bounded by the top of the head, the bottom of the chin, and included the ears. Non-face areas included the area between the outside of the head region and the borders of the entire image (see Figure 1 for an example of interest area parcellation).

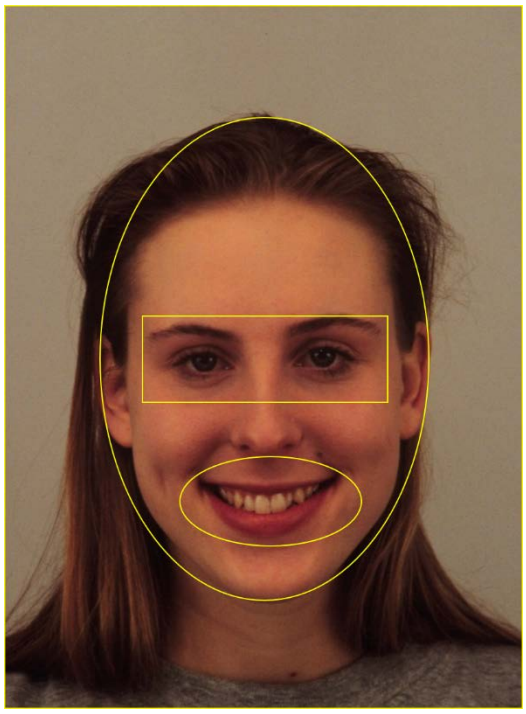

Figure 1. Example of facial region parcellation.

Sample size for mixed models. Simulation studies have identified different sample sizes that are sufficient for mixed-model analyses. Maas and Hox (2005) concluded that only small level-two sample sizes (i.e., < 50) contributed to biased estimates of second-level standard errors. However, Maas and Hox (2005) report that others have recommended more conservative group (i.e., level-two) sizes of at least 100. Our study design included observations (level-one) nested

within participant (level-two). In the present study our level-two sample size was 105 while our number of level-one observations was 51 resulting in approximately 5300 total observations per analysis. As such, our overall sample size falls within the conservative recommendations.

Experiment 1: Dynamic Image (Emotion Identification)

Experiment 1 Task

The dynamic image task incorporated the ADFES stimuli. Participants viewed a series of 51 videos (17 from each of the three target emotions) in a randomized order. Participants were instructed to watch each video and decide which emotion was being portrayed. Following each video, a decision screen appeared containing the four possible responses (*happiness*, *anger, fear*, not sure) as well as the corresponding button on the button box. As with the study by Dalton et al. (2005), in order to reduce the impact of possible performance anxiety participants in Experiment 1 were not explicitly instructed to respond as quickly as possible; participants were simply instructed "Which emotion did you see? Respond by pressing one of these buttons on the button box." Participants were provided with a pictorial representation of the button box on each trial (see Figure 2).

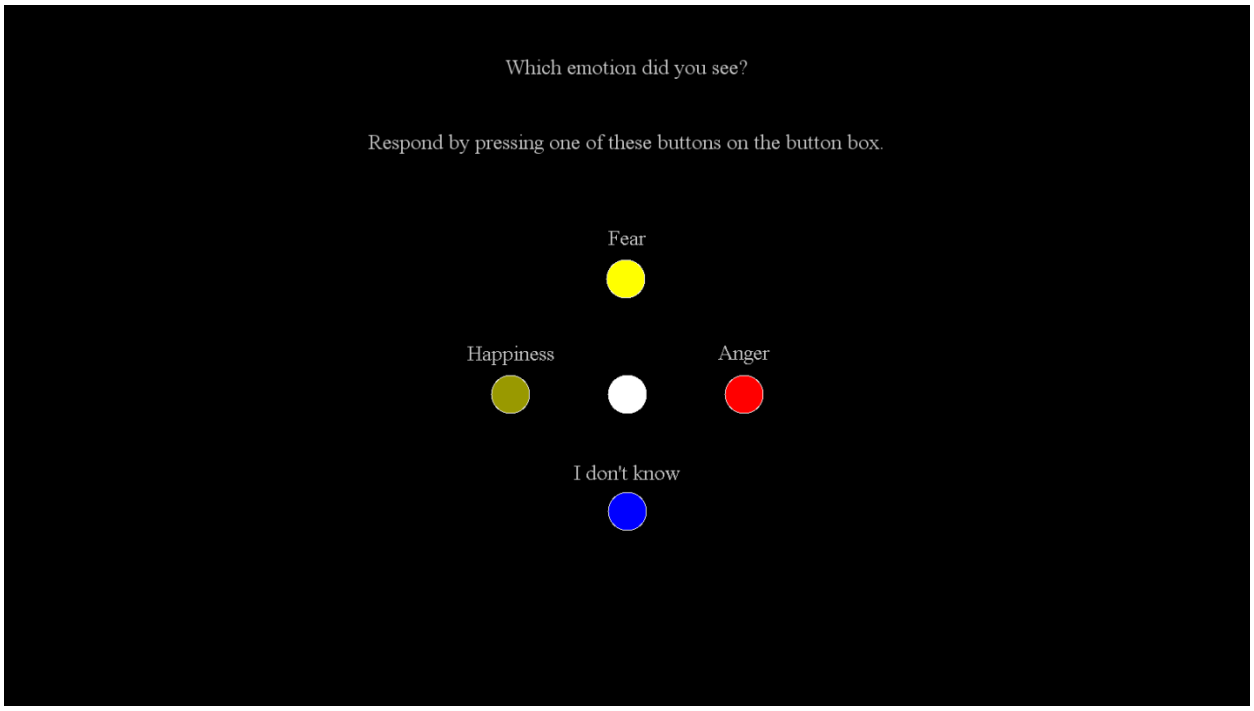

Figure 2. Experiment 1 decision screen.

Experiment 1 Results

Eye-tracking data and behavioral results were analyzed separately. For the eye-tracking data, the dependent variable was the total time that the participant spent fixating the eyes of the stimulus face. For the behavioral data, the two dependent variables were emotion identification response time (RT) and accuracy.

Data were analyzed using linear (or logit, for the accuracy data) mixed-effects models using Stata 13 (StataCorp). We fenced outlying values to be within 2 IQR. Time variables (i.e., RT and interest area dwell time) were routinely log-transformed to meet assumptions of normality due to their exponential distribution. Since grouping variables were not included in the dimensional analysis, symptom questionnaire data were mean-centered to the whole sample for ease in interpretability. For each analysis, two models were fitted to the data. The first model, which we will refer to as the *categorical model*, the predictor variables were Group (Autism [AS] vs. High-Anxiety [HI-ANX] vs. Typical [NT]) and Emotion (*joy, anger, fear*).

The purpose of this model was to explore differences between groups. In the second model, which we will refer to as the *dimensional model*, Emotion was retained as a predictor but the Group variable was replaced with scores on three symptom questionnaires, the AQ, the TAS and the PSQ. These variables index symptoms associated with AS, alexithymia, and anxious apprehension, respectively. The purpose of this model was to identify the source of group differences observed in the first model. That is, if the AS group differs from typically developing controls, can this difference be attributed to anxious apprehension, alexithymia, or autism-specific symptoms. Additionally, we ran an exploratory analysis of sex effects for each model with sex as the sole predictor. There were no significant effects of sex for any of the models. Descriptive statistics for task performance across the three study variables are provided in Table 2.

Eye-tracking results. As hypothesized, in the categorical model the AS group had significantly less dwell time on eye regions compared to both NT ($z = 4.30$, $p < .001$) and HI-ANX ($z = 2.79$, $p = .005$) groups during *joy* stimuli (see Table 3). Bonferroni-corrected post-hoc comparisons indicated this was also true for all emotions combined ($ps < .05$). There was a significant simple effect for emotion, with AS participants spending less time viewing eye regions during *joy* stimuli compared with both *anger* ($z = 8.03$, $p < .001$) and *fear* ($z = 11.30$, $p < .001$). Bonferroni-corrected post-hoc comparisons indicated that this was also a significant main effect (i.e., true for all participants combined, regardless of group; $p < .05$).

Table 2

Descriptive Statistics for Experiment 1 Task Performance

	Emotion			
	Joy *M* (*SD*)	Fear *M* (*SD*)	Anger *M* (*SD*)	Combined *M* (*SD*)
AS				
Eye Fixation (ms)	2075.45 (1523.71)	2820.52 (1556.55)	2536.39 (1521.71)	2477.45 (1563.46)
Response Time (ms)	919.58 (765.05)	959.12 (883.27)	1094.77 (978.11)	991.15 (882.39)
Accuracy (% correct)	99.79% (4.58%)	99.16% (9.14%)	92.65% (26.13%)	97.20% (16.51%)
NT				
Eye Fixation (ms)	2964.98 (1351.24)	3510.75 (1283.28)	3348.57 (1273.01)	3274.77 (1322.39)
Response Time (ms)	769.93 (414.54)	850.86 (640.26)	888.76 (645.10)	836.52 (578.64)
Accuracy (% correct)	99.75% (5.00%)	99.00% (9.96%)	94.99% (21.82%)	97.91% (14.29%)
HI-ANX				
Eye Fixation (ms)	2581.72 (1172.41)	3343.48 (1063.16)	3063.93 (1123.79)	2996.37 (1163.25)
Response Time (ms)	797.54 (652.69)	840.97 (409.27)	852.03 (534.38)	830.18 (541.43)
Accuracy (% correct)	99.56% (6.59%)	98.91% (10.39%)	96.73% (17.80%)	98.40% (12.54%)

Note: AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group; ms = milliseconds.

Table 3

Categorical Model of Experiment 1 Eye Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
Diagnosis				
NT	0.49	0.11	4.30	< .001
HI-ANX	0.36	0.13	2.79	.005
Emotion				
Anger	0.25	0.03	8.03	< .001
Fear	0.35	0.03	11.30	< .001
Diagnosis × Emotion				
NT × Anger	-0.09	0.04	-2.22	.03
NT × Fear	-0.13	0.04	-3.28	.001
HI-ANX × Anger	-0.04	0.04	-0.90	.37
HI-ANX × Fear	-0.02	0.04	-0.51	.61
Constant	7.36	0.09	82.19	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.18	0.003	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*).
SE = standard error; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

There were also significant Group × Emotion interactions. The difference in eye fixation between *joy* and the two negative emotions (i.e., *anger* and *fear*) was significantly more pronounced for the AS group compared to the NT group (z = -2.22, p = .03; z = -3.28, p = .001; see Figure 3). In the dimensional model, AQ was the only significant predictor of eye area dwell time and had a negative relationship (z = -2.59, p = .01) for *joy* stimuli, meaning at higher levels of autism symptoms dwell dime decreased. There were significant Emotion × AQ and Emotion × TAS interactions for *fear* (z = 3.09, p = .002) and *anger* (z = 2.83, p = .005), respectively (see Table 4). The Emotion × AQ interaction suggests that the negative linear relationship between eye fixation and questionnaire data was less pronounced for *fear* compared with *joy*. In other words, the difference in eye fixation between *fear* and *joy* was more pronounced at higher levels

of AQ symptoms (see Figure 4). For the Emotion × TAS interaction, the difference between *joy* and *anger* was more pronounced at higher levels of alexithymia symptoms.

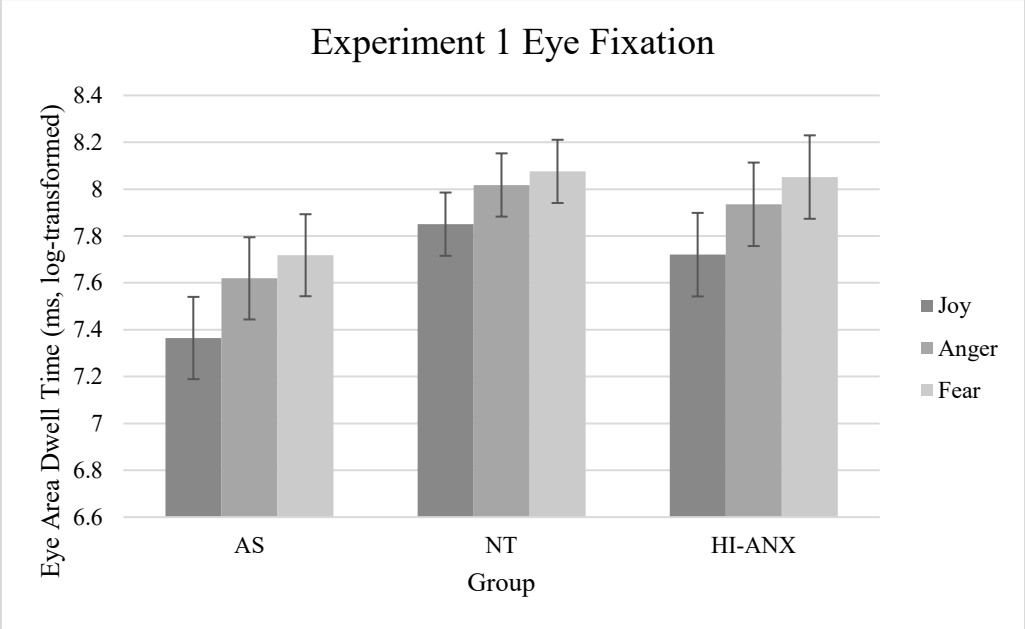

Figure 3. Bar graph of eye fixation between groups. Among all participants combined, individuals fixated eyes less during *joy* trials compared to both *fear* and *anger*. This difference between *joy* and the two negative emotions was more pronounced for the AS group compared to the NT group. *Note:* AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group; error bars represent 95% confidence interval.

Table 4

Dimensional Model of Experiment 1 Eye Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
TAS†	-0.003	0.005	-0.59	.55
AQ†	-0.018	0.007	-2.59	.01
PSQ†	0.002	0.004	0.60	.55
Emotion				
Anger	0.204	0.016	12.82	< .001
Fear	0.280	0.016	17.72	< .001
Emotion × TAS†				
Anger	0.005	0.002	2.83	.01
Fear	0.002	0.002	1.22	.22
Emotion × AQ†				
Anger	0.002	0.002	0.74	.46
Fear	0.007	0.002	3.09	.002
Emotion × PSQ†				
Anger	< 0.001	0.001	0.20	.84
Fear	< 0.001	0.001	0.22	.83
Constant	7.737	0.046	167.71	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.17	0.004	-	-

Note: Reference groups: Joy (*Emotion*).
SE = standard error; TAS = Toronto Alexithymia Scale-20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; † = mean-centered.

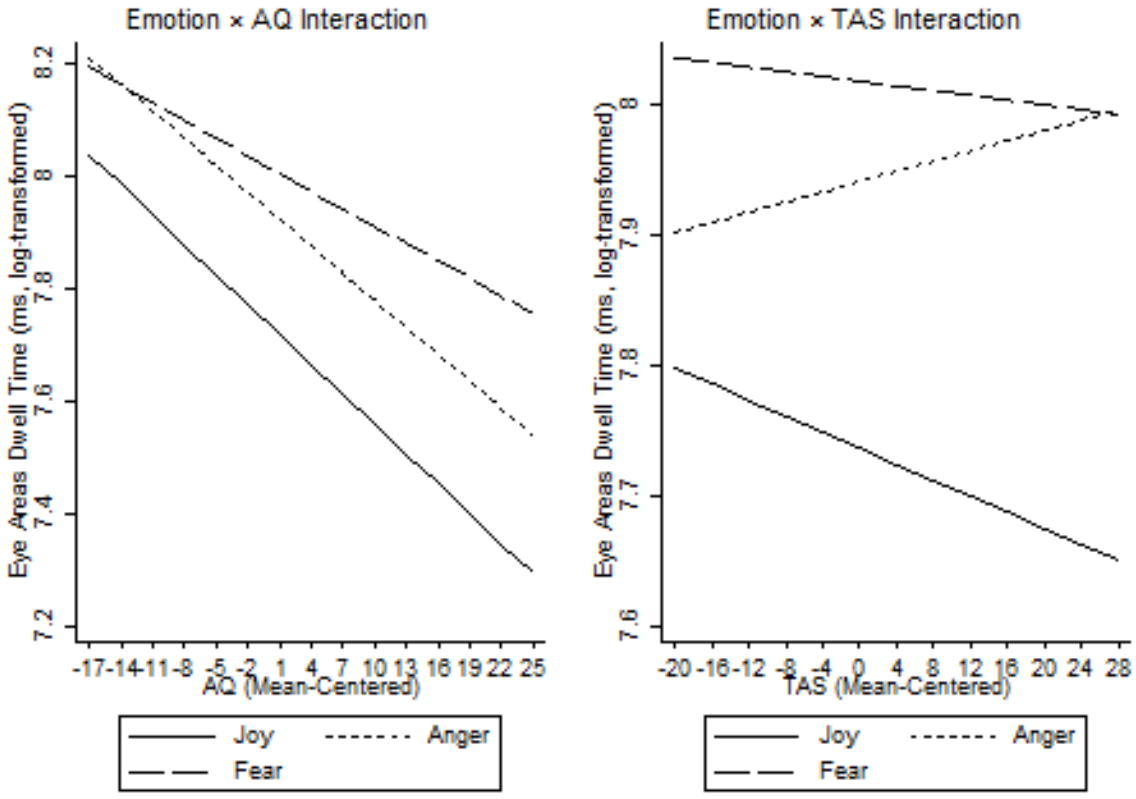

Figure 4. Graphical representation of Emotion × Questionnaire interactions. There were significant interactions for eye fixation, compared to *joy* stimuli. For the AQ, the difference between *joy* and *fear* was larger at higher levels of autism symptoms. For the TAS, the difference between *joy* and *anger* was larger at higher levels of alexithymia symptoms. Note: AQ = Autism Quotient; TAS = Toronto Alexithymia scale.

Overall, the results of the dimensional model suggest that reduced eye fixation in the AS group can be attributed to higher levels of autism symptoms and not to alexithymia or anxious apprehension symptoms.

Behavioral results.

Response time. In the categorical model, the AS group had a significantly slower response time compared with the NT group for *joy* stimuli (see Table 5; $z = -1.97$, $p = .048$). There was also a simple effect for emotion such that AS participants responded more slowly to *anger* compared to *joy* stimuli ($z = 4.34$, $p < .001$; see Figure 5). There were no significant

Group × Emotion interactions (see Table 5). In the dimensional model (see Table 6), the response times for *joy* stimuli were significantly lower compared to both *anger* and *fear* (z = 6.74, $p < .001$; $z = 3.55$, $p < .001$). PSQ scores were negatively related to response time (z = -1.99, $p = .047$).

Table 5

Categorical Model of Experiment 1 Response Time (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
Diagnosis				
NT	-0.12	0.06	-1.97	.048
HI-ANX	-0.09	0.07	-1.33	.19
Emotion				
Anger	0.12	0.03	4.34	< .001
Fear	0.02	0.03	0.88	.38
Diagnosis × Emotion				
NT × Anger	-0.02	0.03	-0.47	.64
NT × Fear	0.04	0.03	1.22	.22
HI-ANX × Anger	-0.06	0.04	-1.64	.10
HI-ANX × Fear	0.05	0.04	1.21	.23
Constant	6.67	0.05	133.10	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.18	0.003	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*).
SE = standard error; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

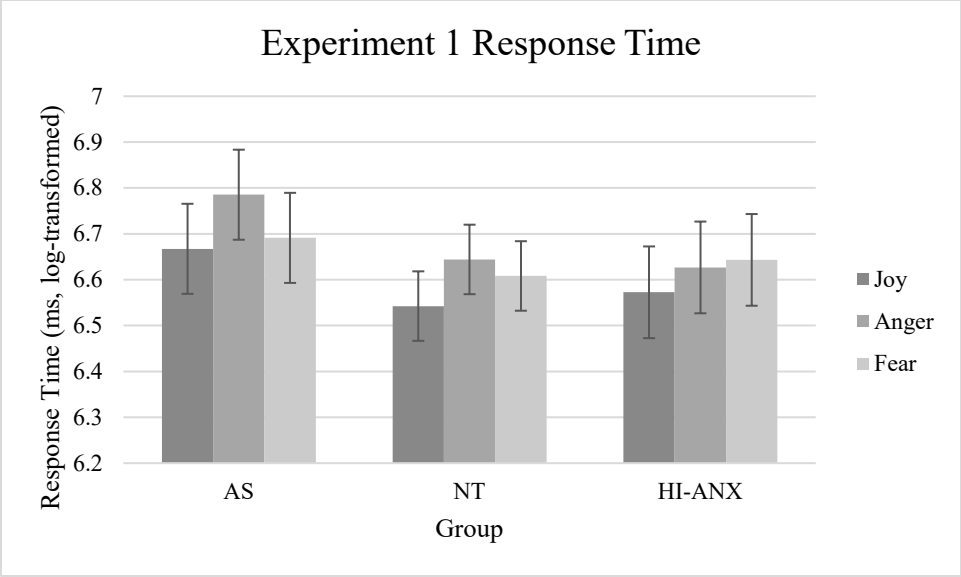

Figure 5. Bar graph of response time between groups. There was a significant main effect for emotion (*anger* > *joy*) among all participants. There were no Group × Emotion interactions. *Note:* AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group; error bars represent 95% confidence interval.

Table 6

Dimensional Model of Experiment 1 Response Time (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
TAS†	0.005	0.003	1.66	.10
AQ†	0.004	0.004	1.05	.29
PSQ†	-0.004	0.002	-1.99	.047
Emotion				
Anger	0.101	0.015	6.74	< .001
Fear	0.053	0.015	3.55	< .001
Emotion × TAS†				
Anger	0.001	0.002	0.41	.68
Fear	-0.004	0.002	-2.64	.01
Emotion × AQ†				
Anger	0.002	0.002	0.94	.35
Fear	0.005	0.002	2.19	.03
Emotion × PSQ†				
Anger	-0.003	0.001	-2.29	.02
Fear	< 0.001	0.001	-0.43	.67
Constant	6.58	0.03	242.56	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.17	0.004	-	-

Note: Reference groups: Joy (*Emotion*).
SE = standard error; TAS = Toronto Alexithymia Scale-20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; † = mean-centered.

There were additional significant interactions between emotion type and the three symptom questionnaires. For the AQ, the difference between *joy* and *anger* was present at higher levels of autism symptoms, but not at lower levels (see Figure 6). For the TAS the opposite was true (see Figure 7). For the PSQ, individuals reporting more anxious apprehension responded more quickly to all emotions (compared to individuals reporting lower symptoms), but this was especially true for *anger* stimuli (see Figure 8).

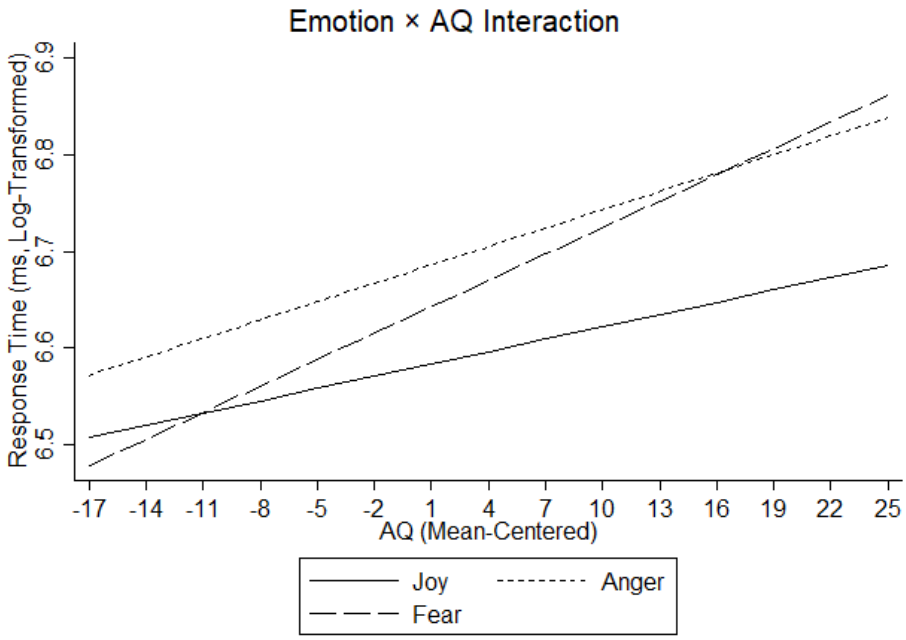

Figure 6. Depiction of the Emotion × Autism Quotient (AQ) interaction showing a greater response time difference between *joy* and *fear* at higher levels of autism symptoms.

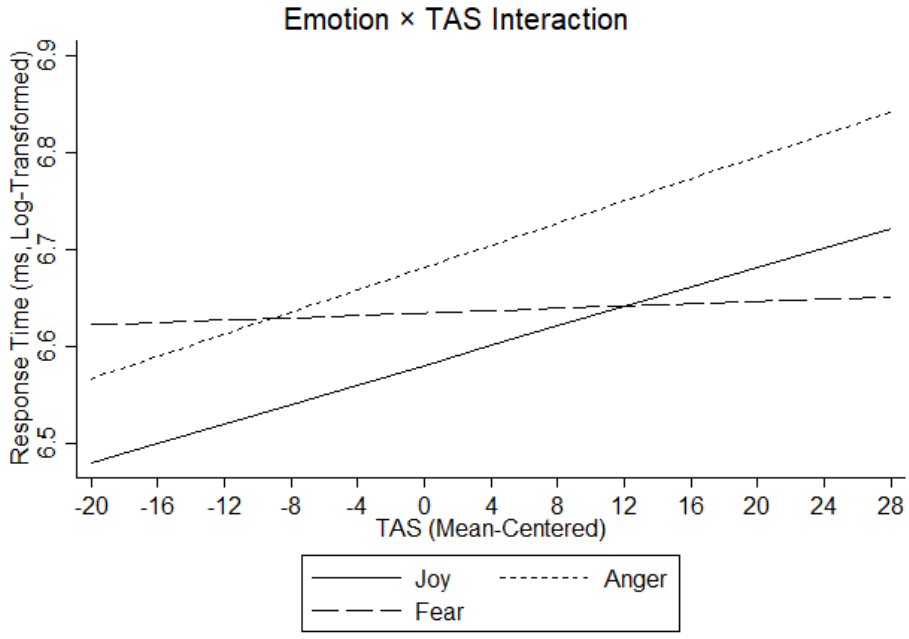

Figure 7. Depiction of the Emotion × Toronto Alexithymia Scale (TAS) interaction showing a greater response time difference between *joy* and *fear* at lower levels of alexithymia symptoms.

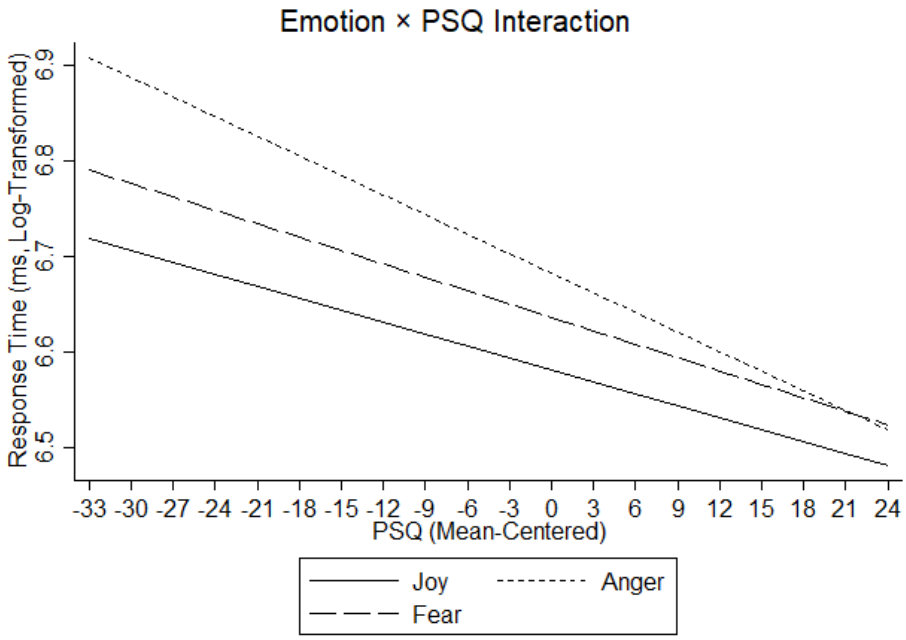

Figure 8. Depiction of the Emotion × Penn State Worry Questionnaire (PSQ) interaction showing that individuals reporting more anxious apprehension responded more quickly to all emotions (compared to individuals reporting lower symptoms), but this was especially true for *anger* stimuli.

Overall, the results of the dimensional model suggest that slower response times in the AS group can be attributed to higher anxious apprehension levels. The absence of an RT difference between the AS and HI-ANX groups is consistent with this interpretation.

Accuracy. In the categorical model, the AS group did not differ significantly from either comparison group in overall accuracy (z = -0.16, p = .88; z = -0.35, p = .73). However, there appeared to be a ceiling effect for accuracy with mean accuracy between groups ranging between 97% and 98% (see Table 2). Participants in the AS group were less accurate for *anger* than *joy* stimuli (z = -3.72, p < .001). This was also a significant main effect (for participants combined) according to post-hoc Bonferroni-corrected pairwise comparisons (z = -6.20, p < .001). There were no significant Group × Emotion interactions (see Table 7).

Table 7

Categorical Model of Experiment 1 Emotion Identification Accuracy

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
Diagnosis				
NT	-0.21	1.30	-0.16	.88
HI-ANX	-0.47	1.34	-0.35	.73
Emotion				
Anger	-3.80	1.02	-3.72	< .001
Fear	-1.41	1.12	-1.25	.21
Diagnosis × *Emotion*				
NT × Anger	0.63	1.26	0.50	.62
NT × Fear	-0.01	1.38	< 0.001	.996
HI-ANX × Anger	1.63	1.28	1.27	.20
HI-ANX × Fear	0.46	1.41	0.32	.75
Constant	7.16	1.07	6.67	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.18	0.003	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*).
SE = standard error; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

In the dimensional model, none of the three symptom predictor variables were significant predictors of accuracy. There were significant Emotion × TAS and Emotion × AQ interactions for *fear* compared to *joy*. As TAS scores increased, the difference in accuracy between *joy* and *fear* was less pronounced while the opposite was true for AQ (see Table 8). Overall, the finding of no differences between participant groups in the categorical model was supported by the lack of significant relationships with symptom predictor variable in the dimensional model.

Table 8

Dimensional Model of Experiment 1 Emotion Identification Accuracy

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
TAS†	-0.09	0.07	-1.31	.19
AQ†	0.15	0.12	1.29	.20
PSQ†	-0.02	0.05	-0.39	.70
Emotion				
Anger	-3.57	0.71	-5.00	< .001
Fear	-1.43	0.78	-1.85	.07
Emotion × TAS†				
Anger	0.06	0.06	0.88	.38
Fear	0.15	0.07	2.07	.04
Emotion × AQ†				
Anger	-0.14	0.12	-1.17	.24
Fear	-0.24	0.12	-1.99	.05
Emotion × PSQ†				
Anger	0.02	0.05	0.51	.61
Fear	0.06	0.05	1.19	.23
Constant	7.41	0.76	9.77	< .001
Random Effects				
Subject: Identity				
Constant	0.06	0.009	-	-
Residual	0.18	0.004	-	-

Note: Reference groups: Joy (*Emotion*).
SE = standard error; TAS = Toronto Alexithymia Scale-20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; † = mean-centered.

Experiment 1 Discussion

Individuals with AS spent more time labeling *joy* emotional trials compared to neurotypical controls. However, the presence of higher anxious apprehension symptoms was the only significant dimensional predictor of response time such that individuals with higher self-reported anxious apprehension responded more quickly. There was also a significant positive relationship between autism symptoms and increased response time for *fear* stimuli as evidenced by the significant Emotion × AQ interaction for *fear*. The dimensional results suggest that individuals with low levels of anxious apprehension may be take the most time in processing emotional stimuli. The results of Experiment 1 did not reveal any differences in emotion

identification accuracy between the AS group and either comparison group. This finding is not uncommon in the literature (Jones et al., 2011; Loveland, Bachevalier, Pearson, & Lane, 2008) and may be explained by the relative easiness of the emotional labeling task. However, other explanations may also exist, including a possible lack of emotion identification deficits altogether. As expected, participants with AS demonstrated reduced eye fixation compared to a typically-developing control group. They also fixated on eye regions less than a high-anxiety control group. However, in contrast to previous findings and our hypotheses, the observed differences could be attributed to autism symptoms but not alexithymia.

Experiment 2: Static Image (Change Detection)

Experiment 2 Task

To see whether predictors of eye fixation were consistent between types of tasks and to investigate possible attention biases, participants completed a luminescence change detection task that did not involve labeling emotions. The change detection task used the static KDEF images. Fifty-one *joy*, *anger*, and *fear* stimuli (17 of each emotion) were each paired with a corresponding neutral face, and the two images were presented side-by-side on a computer monitor. There were an equal number of male and female faces and the emotional and neutral faces were presented in a counterbalanced order with an equal distribution of each being present on the right and left. Participants were instructed that they were to detect whether a change took place on the screen. The change was a sudden reduction of the brightness of the entire computer screen that occurred during an active eye movement (saccade). The change constituted a 3.75% reduction in brightness (from 100% to 96.25%). This amount of change was determined from pilot testing. As soon as the participant noticed a change, they were to press a button on an attached button box. Participants were not instructed to use a particular finger to respond.

Following the change, the images remained on the screen for an additional 3 seconds. Participants completed a single training trial prior to starting the task to become familiar with the brightness change and experimental procedure. Additional clarification was provided to participants to assure they understood the task prior to starting. As with Experiment 1, there were not significant effects of sex in the exploratory analyses for Experiment 2.

Experiment 2 Results

In Experiment 2, eye-tracking data were analyzed to explore participants' reactions to emotional faces during the completion of this unrelated perceptual task (luminance change detection). To investigate eye fixation, the dependent variable was the total time that the participant spent fixating the eye regions for each of the two faces present on the screen (Emotional vs. Neutral faces). To investigate the presence of emotional bias, the whole facial region was analyzed as the dependent variable.

All data were analyzed as described in Experiment 1. In the categorical model, the predictor variables were Face Emotionality (Emotional expression vs. Neutral expression), Emotion (i.e., which expression is the emotional face displaying: Joy, Anger, or Fear), and Group (Autism [AS] vs. High-Anxiety [HI-ANX] vs. Typical [TYP]). In the dimensional model, the Group variable was again replaced with scores on three symptom questionnaires, as described for Experiment 1. The Emotion and Face Emotionality variables were retained. Descriptive statistics for Experiment 2 are found in Table 9 (eye fixation) and Table 10 (face fixation).

Table 9

Descriptive Statistics for Experiment 2 Eye Area Dwell Time (In Milliseconds)

	Emotion			
	Joy *M* (*SD*)	Fear *M* (*SD*)	Anger *M* (*SD*)	Combined *M* (*SD*)
AS				
Face Emotionality				
Neutral	1356.72 (1495.82)	1453.36 (1629.09)	1399.33 (1483.11)	1403.18 (1536.25)
Emotion	1279.92 (1343.74)	1367.32 (1410.12)	1319.68 (1416.56)	1322.36 (139.91)
NT				
Face Emotionality				
Neutral	1800.82 (1955.80)	1860.10 (1787.60)	2010.88 (2181.48)	1893.24 (1987.01)
Emotion	1693.49 (1783.14)	1590.36 (1660.20)	1535.53 (1673.46)	1604.76 (1706.30)
HI-ANX				
Face Emotionality				
Neutral	1868.02 (1914.92)	1934.04 (2332.20)	2073.83 (2102.22)	1961.89 (2123.60)
Emotion	1620.09 (2029.76)	1544.25 (1634.27)	1456.07 (1672.90)	1537.74 (1785.15)

Note: AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

Table 10

Descriptive Statistics for Experiment 2 Face Area Dwell Time (In Milliseconds)

	Emotion			
	Joy *M* (*SD*)	Fear *M* (*SD*)	Anger *M* (*SD*)	Combined *M* (*SD*)
AS				
Face Emotionality				
Neutral	2409.11 (2300.96)	2557.04 (2167.09)	2469.96 (2010.00)	2478.71 (2159.23)
Emotion	2106.92 (1702.04)	2155.12 (1742.16)	2138.84 (1737.00)	2133.79 (1726.67)
NT				
Face Emotionality				
Neutral	2850.21 (2564.12)	3050.30 (2451.55)	3133.92 (2691.92)	3014.47 (2575.42)
Emotion	2438.40 (2088.34)	2273.01 (2089.28)	2277.52 (2211.52)	2328.20 (2132.98)
HI-ANX				
Face Emotionality				
Neutral	2980.44 (2355.08)	3073.90 (2790.70)	3236.01 (2528.40)	3100.73 (2564.41)
Emotion	2444.48 (2195.85)	2242.57 (1866.12)	2214.39 (1999.83)	2297.96 (2025.75)

Note: AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

Eye fixation. With the categorical model, there were no significant differences in eye fixation between the AS group and either comparison group (see Table 11). Additionally, there was also no significant effect of emotion. In other words, there were no differences between *joy* and the two negative emotions for eye fixation (for both the emotional and neutral sides combined) with the AS group. There were significant Diagnosis × Face Emotionality × Emotion interactions. However, since they pertain to the attentional bias research question, they will be discussed in the next section.

Table 11

Categorical Model of Experiment 2 Eye Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
Diagnosis				
NT	0.19	0.13	1.50	.13
HI-ANX	0.26	0.14	1.82	.07
Emotion				
Anger	0.001	0.05	0.02	.99
Fear	-0.02	0.05	-0.42	.68
Face Emotionality				
Emotion	-0.10	0.05	-1.79	.07
Diagnosis × Emotion				
NT × Anger	0.13	0.06	1.95	.051
NT × Fear	0.10	0.07	1.52	.13
HI-ANX × Anger	0.11	0.07	1.46	.14
HI-ANX × Fear	-0.01	0.07	-0.15	.88
Diagnosis × Face Emotionality				
NT × Emotion	0.03	0.07	0.51	.61
HI-ANX × Emotion	-0.09	0.07	-1.20	.23
Face Emotionality × Emotion				
Emotion × Anger	0.01	0.07	0.19	.85
Emotion × Fear	0.07	0.07	0.99	.32
Diagnosis × Face Emotionality × Emotion				
NT × Emotion × Anger	-0.23	0.09	-2.40	.01
NT × Emotion × Fear	-0.22	0.09	-2.39	.02
HI-ANX × Emotion × Anger	-0.24	0.10	-2.33	.02
HI-ANX × Emotion × Fear	-0.09	0.10	-0.90	.37
Constant	6.97	0.10	69.93	< .001
Random Effects				
Subject: Identity				
Constant	0.23	0.03	-	-
Residual	0.74	0.01	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*), Neutral (*Face Emotionality*)
SE = standard error; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

Table 12

Dimensional Model of Experiment 2 Eye Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
TAS†	0.005	0.006	0.76	.45
AQ†	-0.017	0.008	-2.14	.03
PSQ†	0.012	0.004	2.98	.003
Face Emotionality				
Emotion	-0.07	0.03	-2.50	.01
Emotion				
Anger	0.10	0.03	3.55	< .001
Fear	0.03	0.03	1.14	.25
Face Emotionality × *Emotion*				
Emotion × Anger	-0.17	0.04	-4.51	< .001
Emotion × Fear	-0.08	0.04	-2.06	.04
Face Emotionality × TAS†				
Emotion	0.002	0.002	1.28	.20
Face Emotionality × AQ†				
Emotion	0.006	0.002	2.50	.01
Face Emotionality × PSQ†				
Emotion	-0.01	0.001	-8.44	< .001
Emotion × TAS†				
Anger	0.001	0.002	0.42	.68
Fear	0.001	0.002	0.37	.71
Emotion × AQ†				
Anger	-0.002	0.003	-0.79	.43
Fear	-0.002	0.003	-0.73	.46
Emotion × PSQ†				
Anger	< 0.001	0.001	0.17	.86
Fear	0.001	0.001	0.38	.70
Constant	7.12	0.054	130.73	< .001
Random Effects				
Subject: Identity				
Constant	0.23	0.04	-	-
Residual	0.72	0.01	-	-

Note: Reference groups: Joy (*Emotion*), Neutral (*Face Emotionality*)
SE = standard error; TAS = Toronto Alexithymia Scale-20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; † = mean-centered.

Although there were no overall group differences in eye fixation, there were significant predictors that emerged in the dimensional model (see table 12). For the neutral side of stimuli, the AQ was a significant predictor of eye fixation and had a negative relationship (z = -2.14, p = .03). The PSQ was also significant predictor, but had a positive relationship with eye fixation (z

= -2.98, p = .003). In other words, as AQ scores increased fixation time decreased and the opposite was true for the PSQ (for the neutral side only).

Attention bias. Individuals in the AS group, fixated neutral faces more than the corresponding emotional faces (z = -3.37, p = .001) during *joy* trials. Post-hoc Bonferroni-corrected pairwise comparisons indicated a significant main effect for Face Emotionality such that individuals, regardless of group or emotion type, fixated neutral pictures longer than the corresponding emotional side (z = 17.8, p < .001). There were also significant Group × Face Emotionality × Emotion interactions (see Table 13). Specifically, the attentional preference for neutral faces was significantly less pronounced in the AS group compared to the NT and HI-ANX groups under certain emotional conditions (i.e., *anger* and *fear* within the NT group and *anger* in the HI-ANX group; see Figure 9).

In the dimensional model, there was again evidence of an overall attentional preference for neutral faces (z = -4.87, p < .001). Participants also spent more time viewing facial regions (neutral and emotional combined) among *anger* (z = 4.43, p < .001) and *fear* (z = 2.61, p = .009) stimuli, compared with *joy* (as opposed to looking at other non-facial locations on the computer screen). There were additional Face Emotionality × Emotion interactions for *anger* (z = -5.37, p < .001) and *fear* (z = -4.17, p < .001) compared to *joy* suggesting an avoidance of negative face stimuli (by focusing more on the corresponding neutral face). Among the study questionnaires, there was a significant positive Face Emotionality × AQ interaction (z = 6.43, p < .001) and a significant negative Face Emotionality × PSQ interaction (z = -12.31, p < .001). In other words, the preference for dwelling on neutral vs. emotional faces was more pronounced at higher levels of PSQ and lower levels of AQ (see Table 14; Figures 10 and 11). Overall, the results of the dimensional model suggest that the absence of an attentional preference for neutral faces in the

AS group can be explained by high levels of autism symptoms combined with low levels of anxious apprehension.

Table 13

Categorical Model of Experiment 2 Face Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
Diagnosis				
NT	0.12	0.11	1.06	.29
HI-ANX	0.22	0.13	1.76	.08
Face Emotionality				
Emotion	-0.16	0.05	-3.37	.001
Emotion				
Anger	0.02	0.05	0.32	.75
Fear	0.03	0.05	0.60	.55
Diagnosis × Face Emotionality				
NT × Emotion	0.02	0.06	0.33	.74
HI-ANX × Emotion	-0.04	0.07	-0.59	.55
Diagnosis × Emotion				
NT × Anger	0.14	0.06	2.29	.02
NT × Fear	0.10	0.06	1.66	.10
HI-ANX × Anger	0.09	0.07	1.35	.18
HI-ANX × Fear	-0.04	0.07	-0.58	.56
Face Emotionality × Emotion				
Emotion × Anger	0.009	0.07	0.13	.90
Emotion × Fear	0.02	0.07	0.32	.75
Diagnosis × Face Emotionality × Emotion				
NT × Emotion × Anger	-0.25	0.08	-2.97	.003
NT × Emotion × Fear	-0.26	0.09	-3.02	.002
HI-ANX × Emotion × Anger	-0.26	0.10	-2.76	.006
HI-ANX × Emotion × Fear	-0.16	0.10	-1.6	.11
Constant	7.51	0.09	84.55	< .001
Random Effects				
Subject: Identity				
Constant	0.18	0.03	-	-
Residual	0.70	0.01	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*), Neutral (*Face Emotionality*)
SE = standard error; NT = Typically Developing Group; HI-ANX = High-Anxiety Group.

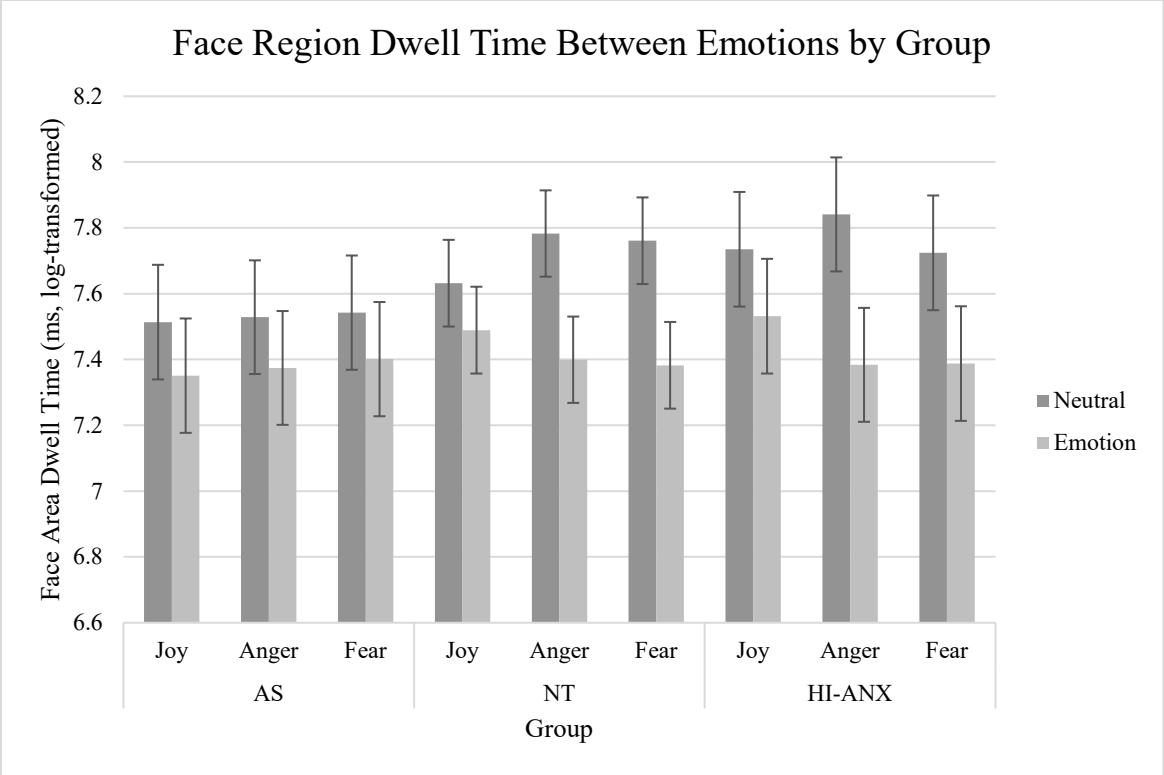

Figure 9. Face region dwell time between emotions by group. There was an apparent attentional bias away from the emotional stimulus during negative emotional stimuli. However, this effect was less pronounced for the AS group. *Note:* AS = Autism Group; NT = Typically Developing Group; HI-ANX = High-Anxiety Group; error bars represent 95% confidence interval.

Table 14

Dimensional Model of Experiment 2 Face Fixation (Log-Transformed)

	Estimate	*SE*	*Z*	*P* value
Fixed Effects				
TAS†	0.01	0.005	1.67	.10
AQ†	-0.02	0.007	-2.68	.007
PSQ†	0.01	0.004	3.40	.001
Face Emotionality				
Emotion	-0.13	0.03	-4.87	< .001
Emotion				
Anger	0.11	0.03	4.43	< .001
Fear	0.07	0.03	2.61	.009
Face Emotionality × *Emotion*				
Emotion × Anger	-0.19	0.04	-5.37	< .001
Emotion × Fear	-0.15	0.04	-4.17	< .001
Face Emotionality × TAS†				
Emotion	0.001	0.002	0.54	.59
Face Emotionality × AQ†				
Emotion	0.01	0.002	6.43	< .001
Face Emotionality × PSQ†				
Emotion	-0.01	-0.001	-12.31	< .001
Emotion × TAS†				
Anger	0.001	.0.002	0.60	.55
Fear	< 0.001	0.002	0.20	.84
Emotion × AQ†				
Anger	-0.002	0.003	-0.66	.51
Fear	< 0.001	0.003	0.18	.87
Emotion × PSQ†				
Anger	0.001	0.001	0.38	.70
Fear	< 0.001	0.001	0.05	.96
Constant	7.60	0.05	157.06	< .001
Random Effects				
Subject: Identity				
Constant	0.18	0.03	-	-
Residual	0.67	0.01	-	-

Note: Reference groups: Autism Group (*Diagnosis*), Joy (*Emotion*), Neutral (*Face Emotionality*)
SE = standard error; TAS = Toronto Alexithymia Scale-20; AQ = Autism Quotient; PSQ = Penn State Worry Questionnaire; † = mean-centered.

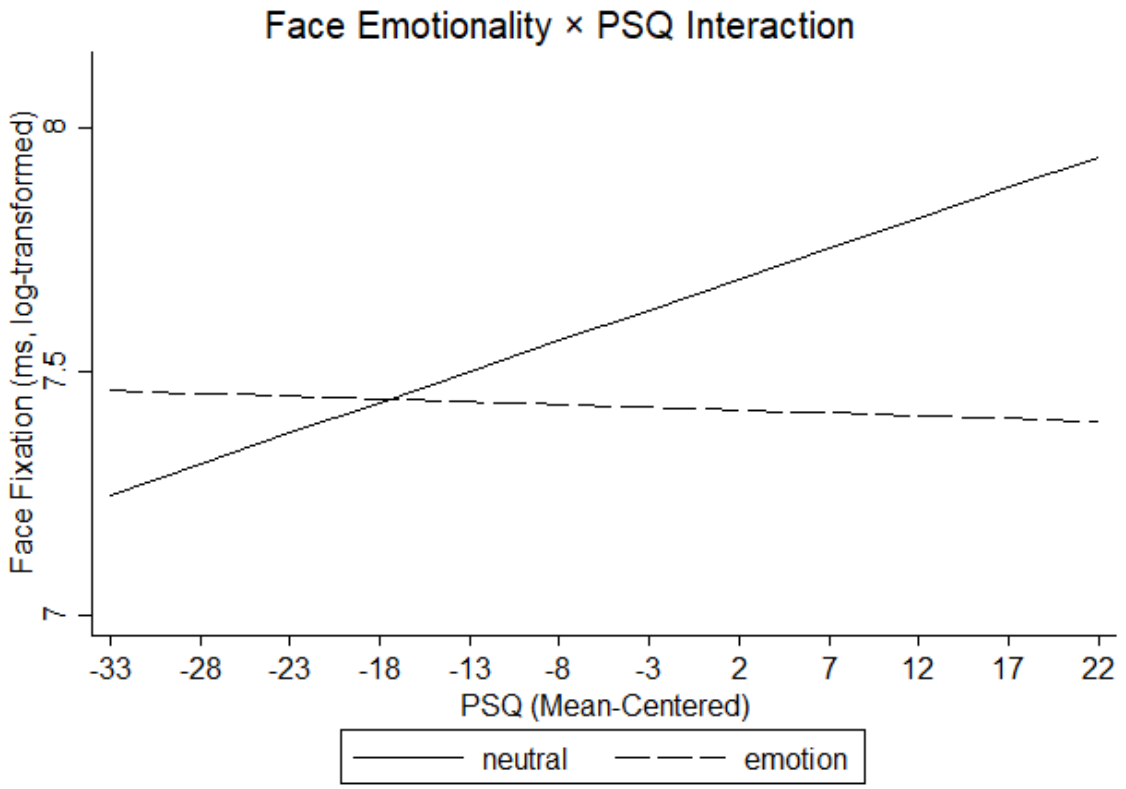

Figure 10. Face Emotionality × PSQ interaction. The amount of attentional bias (neutral > emotion) increases at higher levels of PSQ scores. *Note:* PSQ = Penn-State Worry Questionnaire.

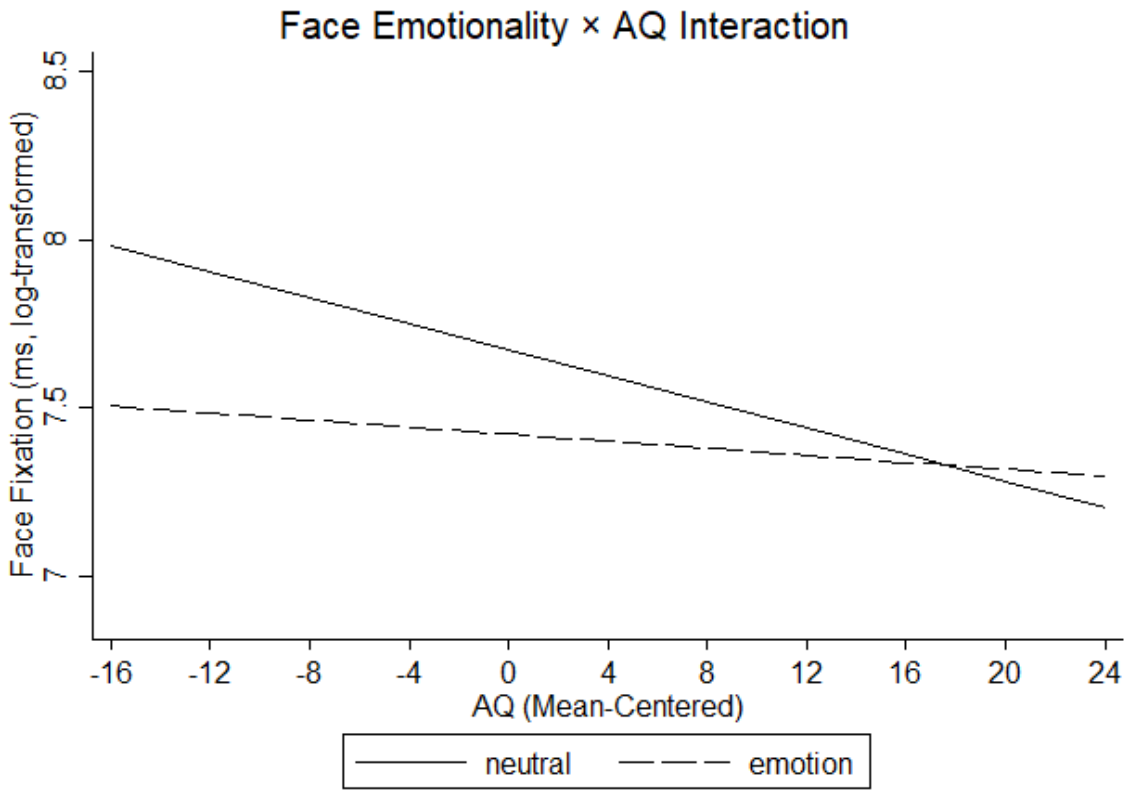

Figure 11. Face Emotionality × AQ interaction. The amount of attentional bias (neutral > emotion) decreases at higher levels of AQ scores. *Note:* AQ = Autism Quotient.

Experiment 2 Discussion

Contrasting the results of Experiment 1, there were no differences in eye fixation between participant groups during a task which did not require explicit emotional processing, although there were also differences in stimuli (dynamic vs. static) which may have also contributed to the lack of group differences). However, within the dimensional model, autism symptoms were negatively related to face fixation while anxious apprehension symptoms showed a positive relationship. Thus, it is possible that the lack of group differences could be due to a competing influence of comorbid levels of anxious apprehension in some of the autism group. There was also an unexpected finding that participants focused more on non-facial regions during *joy*

emotion trials. This was perhaps due to less emotional salience of the *happy* trials compared to negative (or threatening) emotion trials; however, additional studies that directly compare salience levels of emotional stimuli are needed to test this initial hypothesis.

The other major finding from Experiment 2 was an attentional avoidance of negative emotions, with participants spending more time focusing on the corresponding neutral images during these trials. The categorical results suggested that the NT group (i.e., low in symptoms of autism and anxious apprehension) demonstrated the largest avoidance of negative emotions. However, the results of the dimensional model clarified the findings by revealing an attentional avoidance of negative stimuli at lower levels of autism symptoms and *higher* levels of anxious apprehension symptoms.

General Discussion

The primary finding, consistent across two different face processing tasks, was that dimensional symptoms of AS, but not alexithymia, predicted the amount of time participants fixated eye regions of the dynamic (Experiment 1) or static (Experiment 2) face stimuli. Indeed, both experiments highlighted autism symptom level (from the AQ) as a significant dimensional predictor after controlling for overlapping anxious apprehension and alexithymia symptoms. Autism symptoms, as measured by the AQ, best explained the observed reduced eye fixation finding in a traditional emotion recognition paradigm. Although there were no group differences in eye or face fixation within the change detection task, the dimensional model revealed a similar negative relationship between autism symptoms and time spent focusing on eye regions while an opposite pattern was true for anxious apprehension symptoms. These contrasting effects of anxious apprehension and AS may explain the lack of overall group differences. Anxious apprehension symptoms were also associated with decreased response time in Experiment 1

while autism symptoms showed the opposite trend. Taken together, the results from both studies suggest that individuals with high autism symptoms combined with low comorbid anxious apprehension display results more consistent with traditional autism-related findings such as reduced eye fixation and slower response speed. These results provide additional support for the need to identify subtypes within AS, such as the presence of anxious apprehension, as well as the importance of utilizing dimensional models to better understand the complex relationships within emotion processing in AS.

The lack of a significant contribution of alexithymia symptoms was contrary to our hypotheses and past research. Differences between our study and that of Bird and colleagues (2011) might account for the differences in significant predictors. Our AS and NT groups had a larger sample size. Additionally, we added a second, high-anxiety comparison group. We also used a dimensional measure of self-reported autism symptoms (i.e., AQ) rather than ADOS total scores as our measure of autism symptoms and thus were able to model the influence of autism symptoms among all participants. Lastly, our use of mixed-effects models adds statistical power as it better accounts for heterogeneity between individuals and is an effective way of analyzing repeated-measures data.

The AS group showed a number of differences compared to the other groups in the processing of emotional stimuli. In Experiment 1 individuals with AS had higher response time compared to typically-developing adults. However, participants were not specifically instructed to answer as quickly as possible in order to avoid the threat of performance anxiety. Because of this, the results cannot provide conclusive evidence of a *deficit* in processing speed, but rather may provide evidence of a real-world delay as individuals are rarely prompted to respond as quickly as they can in typical social interactions. Previous research investigating response time

in children is mixed with some evidence for increased response time in AS (Berggren, Engström, & Bölte, 2016; Brown, 2017) while the opposite was true when controlling for verbal ability (Fink, Rosnay, Wierda, Koot, & Begeer, 2014). However, the study by Fink et al. (2014) included only four recognition trials per emotion (16 total) and only incorporated female face models.

Additionally, although previous studies have shown a combination of increased response times alongside reduced emotion identification accuracy in AS versus typically-developing controls (Dalton et al., 2005; Sucksmith et al., 2013), in Experiment 1, contrary to our hypotheses, there was no significant main effect for emotion identification accuracy nor any significant dimensional symptom relationships. This provides some evidence that emotion identification and response time may be separate constructs (rather than being causally related or having a shared etiology). However, participants in our study (in contrast to accuracy reported in the Lozier et al. [2014] meta-analysis) had particularly high rates of emotion identification accuracy, ranging from 92% to 99% between emotions, including for *fear* and *anger,* which have previously shown more substantial differences between AS and comparison groups. Several factors may have influenced the high accuracy rates in this study. First, the high accuracy could have been due to the relative ease of the task. In addition, our task required participants to judge emotion expressions from three different emotions whereas other studies have used all six basic emotions (i.e., happiness, fear, anger, surprise, disgust, sadness) increasing both the complexity of facial expressions in addition to more possible choices. We chose to include only three emotions to mitigate task length while also including enough observations per emotion to achieve sufficient statistical power. Of course, the lack of difference between the groups could also be evidence of a lack of emotion identification deficit in AS as well.

Additional studies could expound on our study design to include more emotions and use more difficult emotion identification tasks in order to further investigate emotion identification deficits in AS. For example, Smith, Montagne, Perrett, Gill, and Gallagher (2010) used a paradigm involving varying intensities of dynamic emotional stimuli in adolescents with and without AS. Their stimuli were created using algorithms that created intermediate morphed expressions that ranged in intensity from neutral (0%) to fully emotional (100%). This allowed them to have a range of subtlety in their study from 20% to 100% emotional expression across all six basic emotions. They reported significant group effects with the AS group being less accurate compared to the control group. They also reported a number of trends towards significance for Intensity × Group and Emotion × Intensity × Group interactions; however, they were limited in their statistical power due to low sample sizes (21 AS, 16 typically-developing). Future studies using multiple comparison groups, larger samples sizes, and advanced statistical techniques which are better-suited for repeated-measure designs (i.e., mixed-effects models) could add insight into the emotion identification accuracy with varying levels of intensity and difficulty.

There was partial evidence for our hypothesis regarding a greater effect for negative valence compared to positive valence emotions, especially true for eye fixation in AS compared to NT controls. The lack of consistency in this effect across study variables (i.e., RT and accuracy) and within dimensional models could have been due to several reasons. Response time in emotion processing studies has received less attention compared to accuracy and eye fixation and may not have a similar relationship between positive vs. negative valanced emotions. The lack of difference for accuracy was possibly due to a ceiling effect. The possible interactions between RT and accuracy are also not well understood. In other words, since our

study involved a relatively easy task, using only three of six basic emotions, it may be possible that RTs would be longer in more difficult tasks and particularly when more responses are provided. In general, participants in all groups tended to show a differential effect of negative vs. positive emotions which may have led to the lack of consistency in differences between emotions in the dimensional models. In sum, while there was inconsistent evidence for greater effects of negatively-valanced emotions, there was somewhat consistent evidence for this effect for social gaze between the two tasks.

Another significant finding was the presence of a significant "neutral bias" in the typical group, but no significant bias away from negative emotions in the AS group. A bias away from negative emotions was contrary to our hypothesis. The finding in Experiment 2 of a relationship between anxious apprehension-related attentional avoidance of negative emotions in faces is not novel (Chen, Ehlers, Clark, & Mansell, 2002; Heim-Dreger, Kohlmann, Eschenbeck, & Burkhardt, 2006; Rohner, 2004), although a vigilance (i.e., orientation *towards* threating stimuli) process has also been observed in anxiety (Dodd, Vogt, Turkileri, & Notebaert, 2017; Fox, 2002). Research suggests that both processes may occur together and may be mediated by time, with an initial vigilance towards threatening stimuli followed by subsequent avoidance (Wieser, Pauli, Weyers, Alpers, & Mühlberger, 2009). Studies investigating this so-called "hypervigilance-avoidance hypothesis" suggest that within anxiety there exists an initial hypervigilance towards threatening stimuli followed by a longer period of avoidance when participants view threatening stimuli for longer periods of time (Pflugshaupt et al., 2005; Seefeldt, Krämer, Tuschen-Caffier, & Heinrichs, 2014; Wieser et al., 2009). Therefore, since our viewing task included a longer viewing time, it is possible that highly anxious participants were in the avoidance "phase" of processing the negative emotions. Additionally, the presence

of anxious arousal symptoms (compared to anxious apprehension) may also influence the type of bias seen during these tasks. Future studies could look at the differential effects of subtypes of anxiety to better understand their relationship to emotion processing, including their effect on attentional biases.

In our study, the AS group did not show an emotion-related attentional bias. One possible explanation of the lack of observed attentional bias in the AS group, compared to the NT and HI-ANX groups, could be that they were not considering or being influenced by social-emotional information. Previous research in AS has also found a lack of an attentional bias (albeit a lack of a *towards*-threat bias) in AS with a pictorial social Stroop paradigm (Ashwin, Wheelwright, & Baron-Cohen, 2006). Interestingly, in the current study (Experiment 2), anxious apprehension symptoms were predictive of a more "typical" presentation ("neutral bias") whereas autism symptoms were predictive of "no bias." Thus, if an individual with AS also had high anxious apprehension, the model suggests they would present with a more "typical" neutral bias. This gives evidence to support the presence of comorbid anxiety as a potential "subtype" within AS, particularly for anxious apprehension (see also Rodgers, Glod, Connolly, & McConachie, 2012; van Steensel et al., 2011; White et al., 2009). Our results suggest that future studies could continue to investigate the role of anxious apprehension as well as other dimensions of anxiety (e.g., anxious arousal) in autism spectrum disorder. Additionally, these results, along with other studies from our lab (e.g., Maisel et al., 2016), highlight the importance of considering dimensional characteristics within autism spectrum disorders to identify more nuanced interplay between complex constellations of comorbid emotional and behavioral symptoms.

Our study includes a number of limitations. First, we had a number of different dependent variables. Although mixed-effects models increase statistical power by using all available data and dealing with correlated (i.e., within-subject) observations, the number of analyses still adds to the overall type-I error rate, increasing the possibility that the results were due to chance. Replication studies will be needed to confirm our findings. Second, our clinical control group consisted of college students reporting elevated levels of anxiety and low levels of depression, but formal diagnoses of anxiety disorders were not confirmed. Although this makes it difficult to generalize the categorical results to anxiety disorders, the lack of formal diagnosis matters less for the dimensional models. For the dimensional models (i.e., the primary focus of this study), we were primarily interested in including a set of individuals with a range of emotional symptoms. As such, categorical diagnoses become less important when modeling dimensional effects of our symptom measures on our variables of interest.

Another limitation is the significant differences in sex ratio between the study groups. Within AS there are considerably more males diagnosed than female with approximately four males diagnosed for every female (Fombonne, 2009). There also appears to be more females diagnosed with anxiety disorders compared to males, but with a smaller ratio (i.e., 1:1.7 – 1:1.79; McLean, Asnaani, Litz, & Hofmann, 2011). Furthermore, there is evidence that females are more accurate and have reduced identification latency compared to males (Wingenbach, Ashwin, & Brosnan, 2018). However, Campanella et al. (2012) found that the sex differences during a modified emotional oddball task with EEG were modulated by subclinical levels of alexithymia and depression. Furthermore, alexithymia emerged as a better predictor of N2 latencies and depression for P3b latencies compared to sex. These data suggest that both sex and dimensional characteristics should be investigated. Although our exploratory analyses suggested no overall

effect of sex on the primary dependent variables for the two tasks, we were not able to completely investigate the interplay between sex and emotional symptoms. Future studies should match groups for sex to better investigate these effects.

Our participant groups were not matched on alexithymia levels; however, the overall sample was normally distributed in TAS scores. Also, as exists with the majority of alexithymia-based research, our study is limited by the fact that we relied primarily on self-reported questionnaire data for the symptom measures used in our analyses, although such measures have shown to be useful and appropriate in adult samples with AS (Berthoz & Hill, 2005). However, future research can employ multimethod and multi-informant measures of alexithymia and emotional symptoms including possible performance-based measures, such as the Levels of Emotional Awareness Scale (Lane et al., 2015; Lane, Quinlan, Schwartz, Walker, & Zeitlin, 1990).

Although we controlled for possible comorbid anxious apprehension symptoms, we did not assess participants' level of attention-related problems and cannot rule out attentional influences on our results. There exists a fair amount of overlap between attention-deficit/hyperactivity disorder (ADHD) and AS in both overlapping traits and co-occurring symptoms (Reiersen & Todd, 2008; Taurines et al., 2012). Furthermore, difficulty concentrating is a diagnostic feature of generalized anxiety disorder (American Psychiatric Association, 2013). The influence of possible inattention and poor concentration was not formally assessed with our study sample. It is possible that inattention may have also influenced performance on this task. Future research could expand on our findings to identify other possible mechanisms of action that may explain differences in social-emotional processing. Finally, due to a lack of valence and arousal ratings between the stimuli used in both experiments, the two studies are not directly

comparable. Future research could directly assess the influence of alexithymia on implicit versus explicit emotional processing. Additionally, it is unclear to what extent AS, anxious apprehension, and alexithymia symptoms influence more typical or "real-world" interractions such as frequency, duration, and quallity of communication and eye contact.

Overall, this study suggests that the influence of alexithymia in the processing of social stimuli in AS may not be as ubiquitous as previously thought. The dimensional results suggest possible competing influences of anxious apprehension and autism symptoms across a transdiagnostic sample. The findings give more evidence for the need of identifying subtypes within AS as well as the need to continue to investigate dimensional analyses to better account for overlapping and comorbid participant characteristics.

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Appendix A

Stimuli used in Experiment 1

M01AngerX.avi
M01FearX.avi
M01JoyX.avi
M02AngerX.avi
M02FearX.avi
M02JoyX.avi
M03AngerX.avi
M03FearX.avi
M03JoyX.avi
M04AngerX.avi
M04FearX.avi
M04JoyX.avi
M06AngerX.avi
M06FearX.avi
M06JoyX.avi
M07AngerX.avi
M07FearX.avi
M07JoyX.avi
M08AngerX.avi
M08FearX.avi
M08JoyX.avi
M10AngerX.avi
M10FearX.avi
M10JoyX.avi
M11AngerX.avi
M11FearX.avi
M11JoyX.avi
M12AngerX.avi
M12FearX.avi
M12JoyX.avi

F01AngerX.avi
F01FearX.avi
F01JoyX.avi
F02AngerX.avi
F02FearX.avi
F02JoyX.avi
F03AngerX.avi
F03FearX.avi
F03JoyX.avi
F04AngerX.avi
F04FearX.avi
F04JoyX.avi
F05AngerX.avi
F05FearX.avi
F05JoyX.avi
F06AngerX.avi
F06FearX.avi
F06JoyX.avi
F08AngerX.avi
F08FearX.avi
F08JoyX.avi

Appendix B

Stimuli used in Experiment 2

F10_Anger.JPG
F10_Fear.JPG
F10_Joy.JPG
F10_Neutral.JPG
F13_Anger.JPG
F13_Fear.JPG
F13_Joy.JPG
F13_Neutral.JPG
F17_Anger.JPG
F17_Fear.JPG
F17_Joy.JPG
F17_Neutral.JPG
F19_Anger.JPG
F19_Fear.JPG
F19_Joy.JPG
F19_Neutral.JPG
F21_Anger.JPG
F21_Fear.JPG
F21_Joy.JPG
F21_Neutral.JPG
F23_Anger.JPG
F23_Fear.JPG
F23_Joy.JPG
F23_Neutral.JPG
F24_Anger.JPG
F24_Fear.JPG
F24_Joy.JPG
F24_Neutral.JPG
F25_Anger.JPG
F25_Fear.JPG
F25_Joy.JPG
F25_Neutral.JPG
F27_Anger.JPG
F27_Fear.JPG
F27_Joy.JPG
F27_Neutral.JPG
F30_Anger.JPG
F30_Fear.JPG
F30_Joy.JPG
F30_Neutral.JPG
F35_Anger.JPG
F35_Fear.JPG
F35_Joy.JPG
F35_Neutral.JPG
M13_Anger.JPG
M13_Fear.JPG
M13_Joy.JPG
M13_Neutral.JPG
M14_Anger.JPG
M14_Fear.JPG
M14_Joy.JPG
M14_Neutral.JPG
M16_Anger.JPG
M16_Fear.JPG
M16_Joy.JPG
M16_Neutral.JPG
M17_Anger.JPG
M17_Fear.JPG
M17_Joy.JPG
M17_Neutral.JPG
M18_Anger.JPG
M18_Fear.JPG
M18_Joy.JPG
M18_Neutral.JPG
M21_Anger.JPG
M21_Fear.JPG
M21_Joy.JPG
M21_Neutral.JPG
M22_Anger.JPG
M22_Fear.JPG
M22_Joy.JPG
M22_Neutral.JPG
M25_Anger.JPG
M25_Fear.JPG
M25_Joy.JPG
M25_Neutral.JPG
M28_Anger.JPG
M28_Fear.JPG
M28_Joy.JPG
M28_Neutral.JPG
M29_Anger.JPG
M29_Fear.JPG
M29_Joy.JPG
M29_Neutral.JPG
M31_Anger.JPG
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M33_Anger.JPG
M33_Fear.JPG
M33_Joy.JPG
M33_Neutral.JPG
M34_Anger.JPG
M34_Fear.JPG
M34_Joy.JPG
M34_Neutral.JPG
M35_Anger.JPG
M35_Fear.JPG
M35_Joy.JPG
M35_Neutral.JPG

Appendix C

Other tasks not included in the current study

1. Visual search task (~20 minutes; completed *prior to* Experiment 1 and Experiment 2) – Participants engaged in a visual search task looking at scenes (e.g., a kitchen) and looking for contextual and non-contextual objects.
2. Habituation task (~30 minutes; completed *following* Experiment 1 and Experiment 2) – Participants completed a auditory habituation task while pupillometry data were gathered.