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Eye Gaze and Heart Rate Deceleration as Indices of Attention in Autism: Relations to Anxiety and ASD Symptomology

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By

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Thesis Summary

There is strong evidence that atypical attention patterns are robust indicators of autism spectrum disorder (ASD) in young children. Additionally, anxiety disorders are very prevalent in ASD populations, though the role of anxiety in modulating social attention and threat bias is unclear in children with ASD. While eye gaze methods are typically utilized to measure attention, physiological methods have been deemed a reliable and complementary way to characterize attentional states. As patterns of autonomic dysregulation have been identified in studies of ASD, the use of physiological measures (i.e., heart rate defined sustained attention) is intriguing. The primary goal of the present study was to build upon the visual (eye gaze) and physiological (HRDSA) profiles of attention in children with ASD. The second goal of the study was to clarify the relationship between attention and anxiety in ASD. Participants of this study included 36 preschool-aged children with ASD and 26 typically developing (TD) children. ASD symptomology was evaluated through the Autism Diagnostic Observation Schedule-2 (ADOS-2), while anxiety severity was measured with the Spence Preschool Anxiety Scale (SPAS). Results showed that young children with ASD exhibited reduced gaze towards a stranger in comparison to TD controls; and while anxiety was associated with increased eye gaze in the ASD group, the opposite pattern was found in the TD group. Additionally, while eye gaze and HRDSA methods yielded similar results in the TD group, children with ASD spent considerably more time in HRDSA than they did looking at the stranger. These findings suggest that anxiety may impact attention differently in children with ASD. The observed significant correlation between HRDSA and ASD severity highlights the complex physiological nature of the disorder and calls for continued study of physiological attention in young ASD populations.

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder that is characterized by social communicative impairments, as well as restricted and repetitive patterns of behavior (American Psychiatric Association, 2013). Symptoms of ASD appear early in development and may result in significant social deficits that bring challenges to many aspects of life. Recent studies have demonstrated an upward trend in ASD prevalence, presenting an estimated 1 in 54 prevalence rate for children in the United States (Maenner et al., 2020). While there is no cure for ASD, early identification and intervention have been shown to improve developmental outcomes (Itzchak & Zachor, 2011). Thus, efforts at identifying and characterizing the early signs of ASD in very young children have become a critical public health priority.

There is strong evidence that atypical attention is one of the earliest signs of ASD in infants (Zwaigenbaum et al., 2005). Attention can be defined as the process of concentrating on certain items from an environment while excluding others (Pashler, 1998). Visual attention has been deemed one of the most robust early indicators of ASD, with multiple studies showing that young children with ASD exhibit reduced eye contact, shared attention, and gaze monitoring in comparison to TD children (Ames & Fletcher-Watson, 2010; Elsabbagh et al., 2013). One facet of attention that is particularly relevant to ASD is social attention, which regards how attention is impacted by the presence of other individuals (Vivanti et al., 2017). Social attention is hypothesized to impact the development of critical social cognitive skills such as joint attention, theory of mind, and language development (Ames & Fletcher-Watson, 2010). Since there is evidence of reduced social orienting and monitoring in children with ASD, this warrants further investigation into their attentional patterns and implications for developmental outcomes (Dawson et al., 2004; Schultz, 2005).

Anxiety and Attention in ASD

To clarify the role of attention in ASD and solidify atypical attention as an early marker for ASD, it is critically important to understand how anxiety impacts these mechanisms. This pertinence is due to findings that attentional bias is common in children with anxiety disorders, along with abundant evidence that individuals with ASD are more likely to experience anxiety disorders (Waters et al., 2010). While studies have reported varying ranges of anxiety prevalence estimates, it is generally accepted that anxiety disorders affect approximately 40-80% of individuals with ASD throughout the lifespan (Kent & Simonoff, 2017). While there is less literature regarding studies of anxiety in younger autistic populations, meta-analyses of these studies suggest a comorbidity rate ranging from 11- 84% in children and adolescents with ASD (White et al., 2009).

To explore the role of anxiety in the atypical attentional patterns found in ASD, it is essential to consider studies that have examined these interactions in autistic populations specifically. To investigate these interactions, studies have looked at attentional bias to threats in ASD groups with elevated anxiety. In these studies, attentional bias is commonly quantified by the time it takes participants to orient to a threat and the time it takes to disengage. Past research suggests that individuals with high levels of anxiety struggle to disengage from threats (Abend et al., 2018; Koster et al. 2006), though this pattern is inconsistent within ASD groups. One study examining attentional bias to photographs of threatening faces, measured by response latency, found that despite elevated rates of anxiety in the ASD sample, the ASD group did not demonstrate attentional bias to threats in comparison to TD controls (Hollocks et al., 2013). Similarly, a study of infants by Milosavljevic et al. (2017) found that despite threat bias being significantly correlated with total anxiety scores and anxiety symptoms being significantly greater in the high-risk autism group, those at high risk for ASD did not demonstrate increased threat bias (indexed by enhanced orienting or delayed disengagement) while the low-risk ASD group did. Another study utilizing threatening pictures found that two ASD groups, one with anxiety and one without, did not show differences in disengagement from threats (May et al., 2015). Since anxiety has been found to be correlated with threat bias in TD populations, most studies expected to find a similar threat bias in ASD groups considering their heightened risk for anxiety. However, the results of these studies suggest that the relationship between anxiety and attention may present differently in ASD populations, warranting further investigation into these mechanisms.

Attentional Measures

There are a variety of methods that are used to evaluate attention at a young age, though eye-gaze measures remain prominent. In a controlled environment, automatic eye tracking allows researchers to identify where a participant is looking and for how long. Using corneal reflections of infrared lights, participant gaze can be mapped with high precision and accuracy using remote or head-mounted equipment (Tobii Technology, Stockholm, Sweden; Venker et al., 2020). In naturalistic settings, such as a participant's home, manual gaze-coding measures utilize video recordings to collect similar data. After video recording a participant (making sure to keep their face in view), trained coders can determine gaze location at each time frame based on the visual angle of a participant's eyes and the known locations of objects and people in the environment (Venker et al., 2020). While automatic eye tracking has advantages in its convenience and objectivity, this measure has been found to be more prone to data loss in studies of young children with ASD (Venker et al., 2020). Overall, automatic eye tracking and manual gaze coding capture similar results, though researchers must consider factors such as assessment settings and participant age when implementing these measures.

In addition to behavioral approaches of studying attention in children, physiological methods have also proven to be a reliable and complementary way to characterize attentional states. When the brain is aroused by a stimulus, parasympathetic processes are initiated by cardioinhibitory centers, resulting in a slower heart rate that indicates stimulus engagement and attention (Richards, 2010). Thus, moments of sustained social attention may be characterized by decelerations in heart rate that correspond to longer interbeat intervals (IBIs), a pattern that can be quantified through a recently developed measure called heart rate-defined sustained attention (HRDSA). HRDSA is a well-validated physiological measure that analyzes heart rate decelerations from a baseline to provide incremental information about attentional behavior (Reynolds & Richards, 2008). According to a study by Brez & Colombo (2012), these decelerations have been found to provide a more sensitive metric of sustained attention than behavioral looking alone in infants. Furthermore, previous research has demonstrated that visual looks in infants do not cleanly map onto attention since infants will frequently sustain looking behaviors even when they are not cognitively engaged (Richards, 1985). Thus, HRDSA can provide unique, complementary insight into cognitive states of attention for which behavioral indicators of visual attention cannot account. Additionally, HRDSA is an objective and non-invasive analysis that can easily be incorporated into virtually any behavioral assessment, only requiring that subjects wear a heart rate monitor for the duration of their sessions.

While physiological and eye-gaze methods have both been utilized in studies of childhood attention, significant differences in these measures have been found in ASD studies. A longitudinal study by Tonnsen et al. (2018) examined patterns of HRDSA during a passive looking task in high ASD-risk infants compared to low-risk controls. This study found that HRDSA was able to better predict ASD risk status in comparison to behavioral looking alone. Additionally, more severe ASD symptoms were associated with shallower heart rate decelerations during sustained attention across development (Tonnsen et al., 2018). This result aligns well with Polyvagal theory, which posits that individuals with ASD experience reduced parasympathetic regulation that leaves them in states of inappropriate hyperarousal. These findings emphasize that atypical patterns of attention in high ASD-risk groups can be identified as early as infancy, encouraging further study into attentional profiles in ASD. The predictive power of these results additionally supports the validity of HRDSA as a global physiological measure of attention, though it should be noted that few studies have examined HRDSA past infancy. This has left gaps in our current understanding of how heart rate decelerations develop into childhood and their potential to index attention in children with ASD.

The Present Study

The primary goal of the present study was to characterize eye gaze and HRDSA patterns in children with ASD, while comparing the measures within groups. The second goal of the study was to clarify the relationship between attention and anxiety in ASD. Participants included children between 3 and 5 years of age, which comprised TD and ASD groups. A behavioral measure of attention (i.e., manual gaze-coding) and a physiological measure of attention (i.e., HRDSA) were investigated during a Stranger Approach task, which represents a social and potentially fear-inducing situation. Based on previous research demonstrating reduced social attention in ASD, we predicted that the ASD group would spend less time looking at the stranger during the task compared to the TD group. Additionally, as previous studies fail to show consistent threat bias in children with ASD, we predicted that social gaze would be positively correlated with anxiety in the TD group, but not the ASD group. While blunted heart rates have been found to be correlated with anxiety and ASD symptomology, HRDSA has not yet been studied in preschool-aged children with ASD. Thus, indexing attention with this measure is exploratory. Lastly, due to previous studies suggesting shallower heart rate decelerations in infants, we predicted that the ASD group would exhibit a similar reduced HRDSA depth in comparison to TD controls.

The results of the present study help build upon the HRDSA profiles of both children with ASD and TD children. Examining these profiles in relation to ASD symptomology and anxiety helps us better understand the physiological and cognitive bases for these disorders. Additionally, comparing the results of manual gaze-coding and HRDSA will help guide the use of these measures in future studies of attention in preschool-aged children with ASD. Since HRDSA is an affordable and portable method that can be utilized as early as infancy, the results of this study may further validate and encourage the use of this measure in early screening and intervention efforts.

Methods

Participants

Participants included 36 ASD and 26 TD children between 36 and 66 months of age. Mean ages for the groups were 46.14 months (ASD, s = 8.06) and 44.48 months (TD, s = 10.30). Participants were drawn from a large-scale longitudinal study at the University of South Carolina – Columbia. Children with ASD were recruited statewide through research and medical sites, research registries, as well as parent support and treatment groups, while TD controls were recruited through local pediatrician’s offices and social media. ASD status was confirmed through a clinical diagnosis of ASD, which was determined through the use gold standard diagnostic measures and clinical best estimate procedures. Participants were excluded from the present study if they were born premature (i.e., < 37 weeks gestation) or if they were diagnosed with a genetic condition (e.g., fragile X syndrome, spina bifida), pre-existing medical conditions (e.g., cerebral palsy, seizure disorders), or hearing or vision conditions that would impede their ability to participate in the study. Furthermore, TD children were excluded from the present study if they had a family history of ASD (i.e., first degree relative) or if they were later diagnosed with developmental delay. For the present study, the earliest timepoint with usable heart activity data for the Stranger Approach task at or after 36 months of age was used. Detailed participant demographics are included in Table 1.

Table 1: Demographics of Participants

				Age (months)	**Age (months)**	**IQ**	**IQ**
	N	**Male**	**Female**	**$\bar{x}$**	**s**	**$\bar{x}$**	**s**
ASD	36	31	5	46.1	8.1	58.3	11.9
TD	26	21	5	44.5	10.3	102.7	15.5

The Stranger Approach Task

A social (and potentially fearful-inducing) situation was represented using the Stranger Approach task of the Laboratory Temperament Assessment Battery (Lab-TAB; Goldsmith & Rothbart, 1996). Before the start of the task, children were ensured to be in a neutral emotional state and seated near their caregiver. For the Stranger Approach task, an examiner was dressed in unrecognizable clothes, sunglasses, and a hat. The task consisted of four phases: a baseline phase prior to the stranger entering the room (approximately 30 seconds); an approach phase in which the stranger knocked, greeted the child, then approached the child (approximately 10-15 seconds); a kneel phase in which the stranger silently knelt in front of the child while maintaining a neutral expression (approximately 2 minutes); and a withdraw phase in which the stranger exited the room (approximately 10-15 seconds). While all phases were necessary for HRDSA analysis, the baseline phase was not utilized for eye gaze coding.

Stranger Gaze

The Stranger Approach task was videotaped and coded offline using Datavyu (version 1.5.1, Datavyu Team, 2014). For the entire task, the camera was positioned in front of the child and was focused on their whole face and body. If the child moved away, an examiner would follow the toddler with the camera. Gaze behavior was captured by coding the durations of time spent looking at the stranger, examiner, parent, or away. Gaze was coded continuously with the onset and offset for each gaze code marked across the entire duration of each phase. If the examiner's view of the child was obscured at any point, this was reflected in the code. Stranger Gaze was considered to occur any time the child was looking at the stranger. The proportion of time in stranger gaze was calculated by dividing the sum of stranger gaze by the total duration of the task (excluding the baseline phase).

Behavioral coding of eye gaze was completed by a trained undergraduate research assistant that established initial reliability with a master coder by obtaining 80% agreement with the master coder on three consecutive videos. Agreement, for both initial and ongoing reliability, was defined as both coders marking the onset and offset of the same attention variable (e.g., looking at the parent) within a defined tolerance window of +/- one second (Jansen et al., 2003). To maintain reliability, 20% of the videos coded by the research assistant were coded by the master coder. The reliability comparison revealed a Cohen kappa coefficient of 0.87.

Heart Rate Defined Sustained Attention

Electrocardiogram (ECG) data were collected for the entire duration of the Stranger Approach task with a telemetry-based monitor (CamNtech Ltd., Cambridge, UK). ECG data were inspected by trained research assistants using CardioEdit software to correct arrhythmias and artifacts (Brain-Body Center, University of Illinois at Chicago). Participants were to be removed from the study if more than 10% of their ECG beats were corrected, though this was not observed for any of the participants. Interbeat intervals (IBIs) were extracted from CardioEdit and processed for HRDSA analysis using SPSS software. Baseline IBI was calculated as the median IBI in the 5 beats immediately preceding the Approach phase of the Stranger task. IBIs during the Stranger Approach task (approach, kneel, withdraw) were compared against the baseline IBI to determine periods of HRDSA. HRDSA was defined as a period beginning after 5 successive beats with longer IBIs than baseline, ending after 5 successive beats with shorter IBIs than baseline. The proportion of time in HRDSA was computed by dividing the time spent in HRDSA by the total task time. Average HRDSA deceleration depth was calculated as the relative change of the average IBI while in HRDSA from the baseline. This was computed by taking the difference of the average IBI while in HRDSA and the baseline, then dividing this value by the baseline.

Anxiety Symptom Severity

Anxiety symptom severity was determined using the Spence Preschool Anxiety Scale (SPAS). This measure assesses six domains of anxiety including generalized anxiety, panic/agoraphobia, social phobia, separation anxiety, obsessive compulsive disorder, and physical injury fears (Spence 1997). The scale asks parents to rate the frequency in which their children experience various anxiety symptoms on a 4-point Likert scale. Subscale raw scores for generalized anxiety and social phobia, as well as total anxiety scores, were used for the present study.

ASD Symptom Severity

ASD symptom severity was evaluated using the Autism Diagnostic Observation Schedule-2 (ADOS-2; Lord et al., 2012). The ADOS-2 is a semi-structured, standardized assessment of communication, social interaction, and play, as well as restricted and/or repetitive behaviors. The ADOS-2 was administered by research reliable testers. The ADOS-2 overall scaled scores, ranging from 1-10, were used to quantify ASD symptom severity.

Developmental Level

Developmental level was indexed by the Mullen Scales of Early Learning, a measure designed to evaluate cognitive abilities in infants and preschoolers up to 68 months of age (Mullen, 1995). Intelligence quotients (IQs) were estimated with the Early Learning Composite (ELC) score, which is a composite score of the Visual Reception, Fine Motor, Expressive Language, and Receptive Language subscales. The average ELC scores were 58.3 (ASD, s = 11.89) and 102.7 (TD, s = 15.47), with the Mann Whitney U nonparametric test revealing that IQ was significantly lower in the ASD group ($p < .0001$).

Procedure

Written informed consent was obtained from the parents before enrollment in the study. Procedures and measures were approved by the Institutional Review Board the University of South Carolina. Assessments occurred at the participants home or in a laboratory at the University of South Carolina. The SPAS was completed before the assessment by a caregiver. The Stranger Approach task was administered by at least two trained examiners as part of a larger standardized protocol on temperament and early development in children with neurodevelopmental disorders. Families received monetary compensation and a non-clinical developmental report for their participation.

Statistical Analysis Plan

Demographics and Group Matching

All statistical analyses were performed using SAS OnDemand for Academics software (SAS Institute Inc, Cary NC, 2021). The PROC UNIVARIATE procedure was used to assess normality for demographic variables (age and developmental level). Since it was found that these variables were not normally distributed within the ASD and TD groups, the PROC NPAR1WAY procedure was used for Mann Whitney U nonparametric tests of group matching. Mean ages were 46 months (s = 11.9) for ASD group and 44 months (s = 10.3) for the TD group, while mean Mullen IQs were 58.3 (s = 11.9) for the ASD group and 102.7 (s = 15.5) for the TD group. The results of the nonparametric tests indicated that although the mean ages of the groups were not statistically different, age and developmental level were not matched between the ASD and TD group.

Attentional Profiles

The PROC TTEST procedure was used to perform difference of means tests for three variables: (1) proportion of time looking at the stranger, (2) proportion of time in HRDSA, and (3) depth of HRDSA. Equality of variance between the ASD and TD groups was assessed with Levene's F test, which determined whether pooled variances would be utilized. Descriptive statistics (mean and standard deviation) and p-values from these tests were used to guide comparisons of attention between groups and attentional measures within groups.

Additionally, Pearson correlations between the three attentional variables (stranger gaze, HRDSA, and HRDSA depth) were computed within groups using the PROC CORR procedure.

This was done to address how well eye gaze and HRDSA measures mapped onto each other in the ASD and TD groups.

Correlations with Anxiety and ASD Symptomology

To explore the role of anxiety and ASD severity in modulating attention, we individually ran Pearson correlations of three attentional variables (stranger gaze, HRDSA, and HRDSA depth) with the ASD severity and anxiety variables (ADOS CSS score, Spence Social Anxiety raw score, Spence Generalized Anxiety raw score, and Spence Total Anxiety raw score). Additional correlations were also ran for the total number of looks to the stranger and the median duration of these looks to better assess the presence of threat bias. Scatter plots of these correlations were generated to verify linearity and identify outliers.

Results

Attentional Profiles

Table 2: Group Mean Percentages for Attentional Variables

Variable	ASD M (SD)	TD M (SD)	*p*
Stranger Gaze	21.94 (16.19)	34.12 (15.67)	0.0044**
HRDSA	34.21 (31.45)	36.14 (24.97)	0.80
HRDSA Depth	8.67 (4.25)	8.40 (3.32)	0.80

Table 2. Mean values and standard deviations for the primary Stranger Approach variables (Stranger Gaze, HRDSA, and HRDSA Depth). These values are grouped by ASD status, and p-values are listed from pooled t-tests.

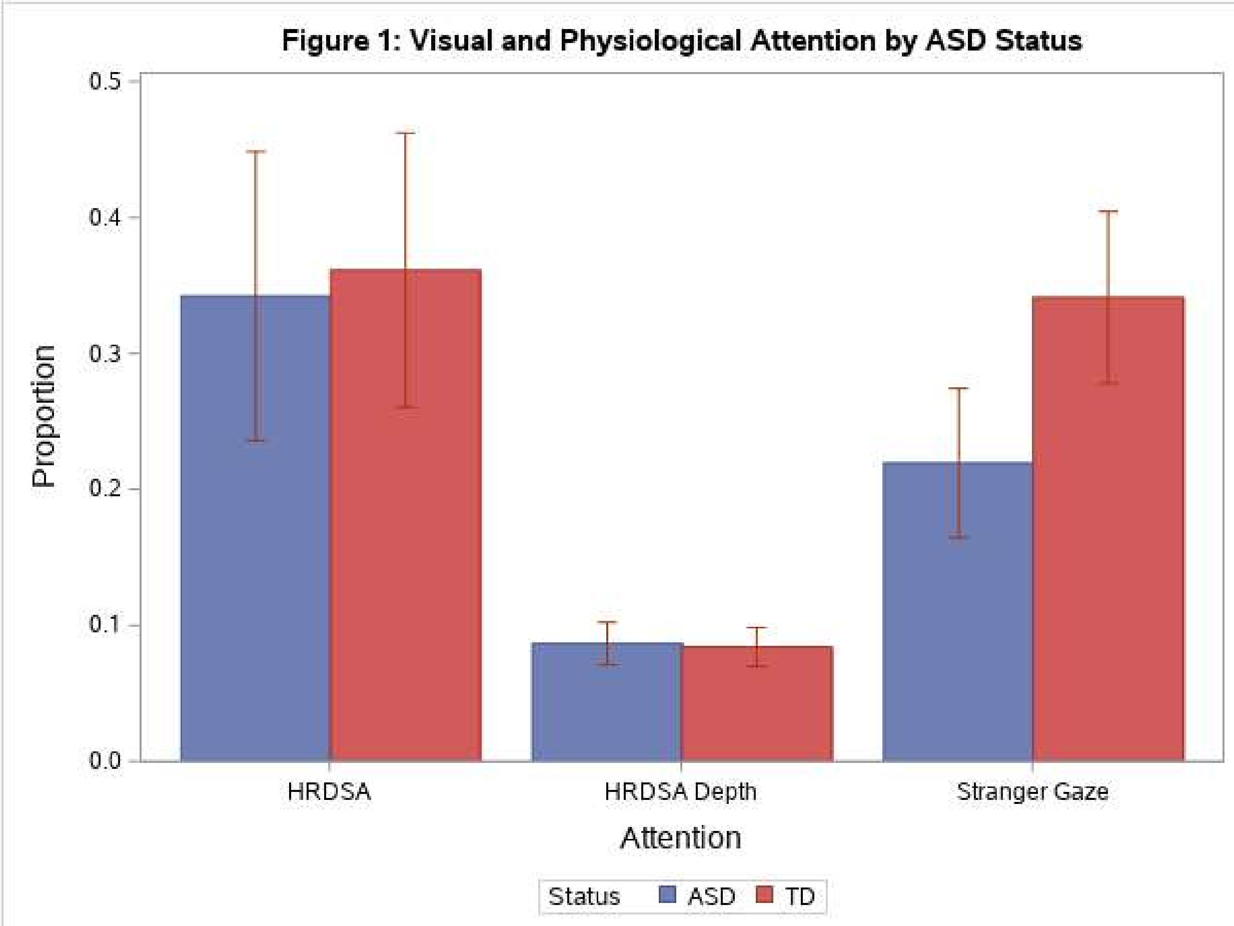

Figure 1. Vertical bar chart of Stranger Approach variable means with 95% confidence limit. Corresponding values shown in Table 2.

Group Differences in Attentional Variables

Difference of means tests indicated that the proportion of time looking at the stranger during the Stranger Approach task was significantly less in the ASD group compared to TD controls (p = .0044**). Proportions of time spent in HRDSA and average HRDSA depths were very similar between groups. While the TD group exhibited similar proportions of time in visual attention and HRDSA, the ASD group spent considerably more time in HRDSA than they did looking at the stranger.

Table 3: Correlations between Attentional Variables				
	HRDSA		HRDSA Depth	
	ASD	TD	ASD	TD
Variable	r (*p*)	r (*p*)	r (*p*)	r (*p*)
Stranger Gaze	-.21 (.22)	-0.014 (.95)	-.055 (.77)	.26 (.17)
HRDSA			.62 (0002)**	.52(.011)*

Table 3. Results from Pearson correlations between Stranger Approach variables. Correlation coefficients (r) and p-values (*p*) are included, grouped by ASD status.

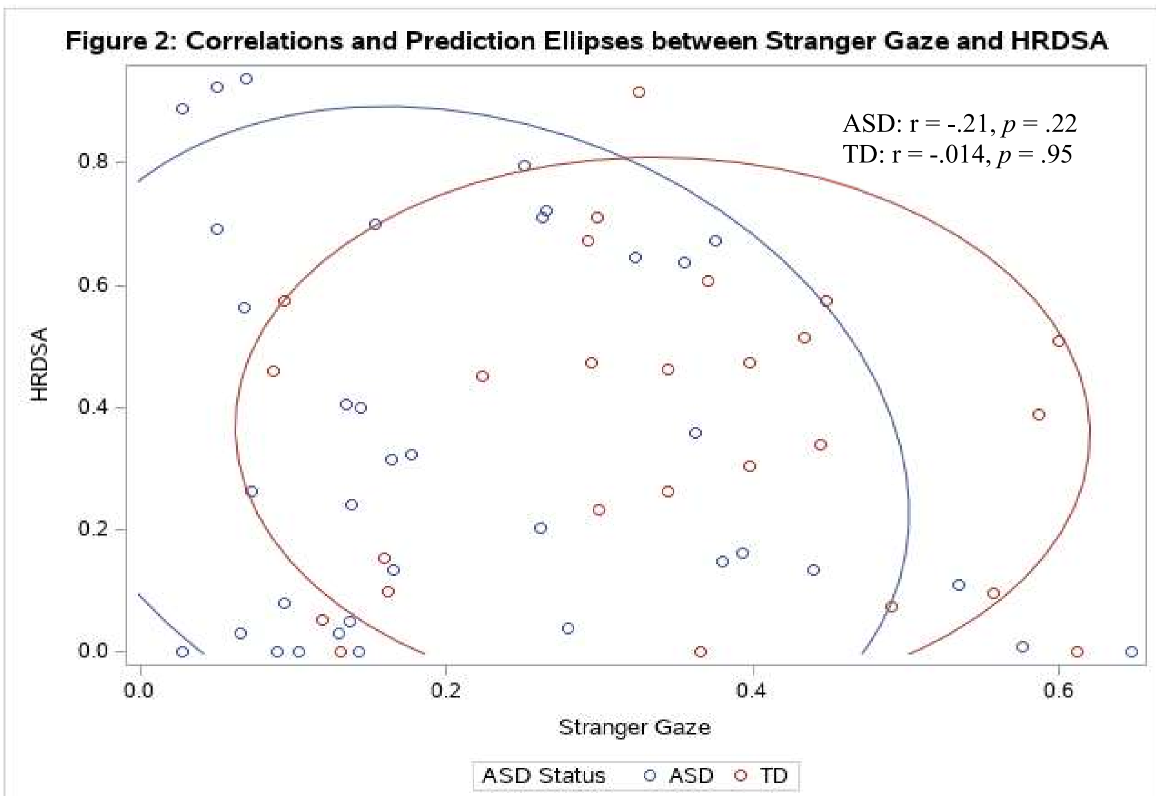

Figure 2. Scatterplots and 75% prediction ellipses to visualize correlations between Stranger Gaze and HRDSA variables.

Correlations between Attentional Variables

No significant correlations were found between visual (stranger gaze) and physiological (HRDSA) attention in either the ASD or TD groups. Significant positive correlations were revealed between HRDSA and HRDSA depth in both the ASD (r = .62, p < .001) and the TD (r = 52, *p* = .011) groups, though this finding was expected as depth calculations were dependent upon HRDSA values.

Correlations with ASD Symptomology and Anxiety

Table 4: Correlations between Attentional Variables and ADOS/Anxiety

	ADOS		**Social Anxiety**	
	ASD	**TD**	**ASD**	**TD**
Variable	**r (*p*)**	**r (*p*)**	**r (*p*)**	**r (*p*)**
Stranger Gaze	-.28 (.10)	.19 (.37)	.38 (.03)*	-.32 (.12)
HRDSA	.36 (.0312)*	.07 (.72)	-.20 (.26)	.15 (.48)
HRDSA Depth	.43 (.0157)*	.36 (.097)	-.01 (.96)	-.02 (.93)
	Generalized Anxiety		**Total Anxiety**	
	ASD	**TD**	**ASD**	**TD**
Variable	**r (*p*)**	**r (*p*)**	**r (*p*)**	**r (*p*)**
Stranger Gaze	.35 (.043)*	-.24 (.26)	.53 (.0014)**	-.40 (.0496)*
HRDSA	-.32 (.07)	-.20 (.33)	-.17 (.35)	-.04 (.83)
HRDSA Depth	-.01 (.98)	-.18 (.42)	.05 (.82)	.00 (.99)

Table 4. Results from Pearson correlations between Stranger Approach variables and ASD severity and anxiety raw scores. Correlation coefficients (r) and p-values (*p*) are included, grouped by ASD status.

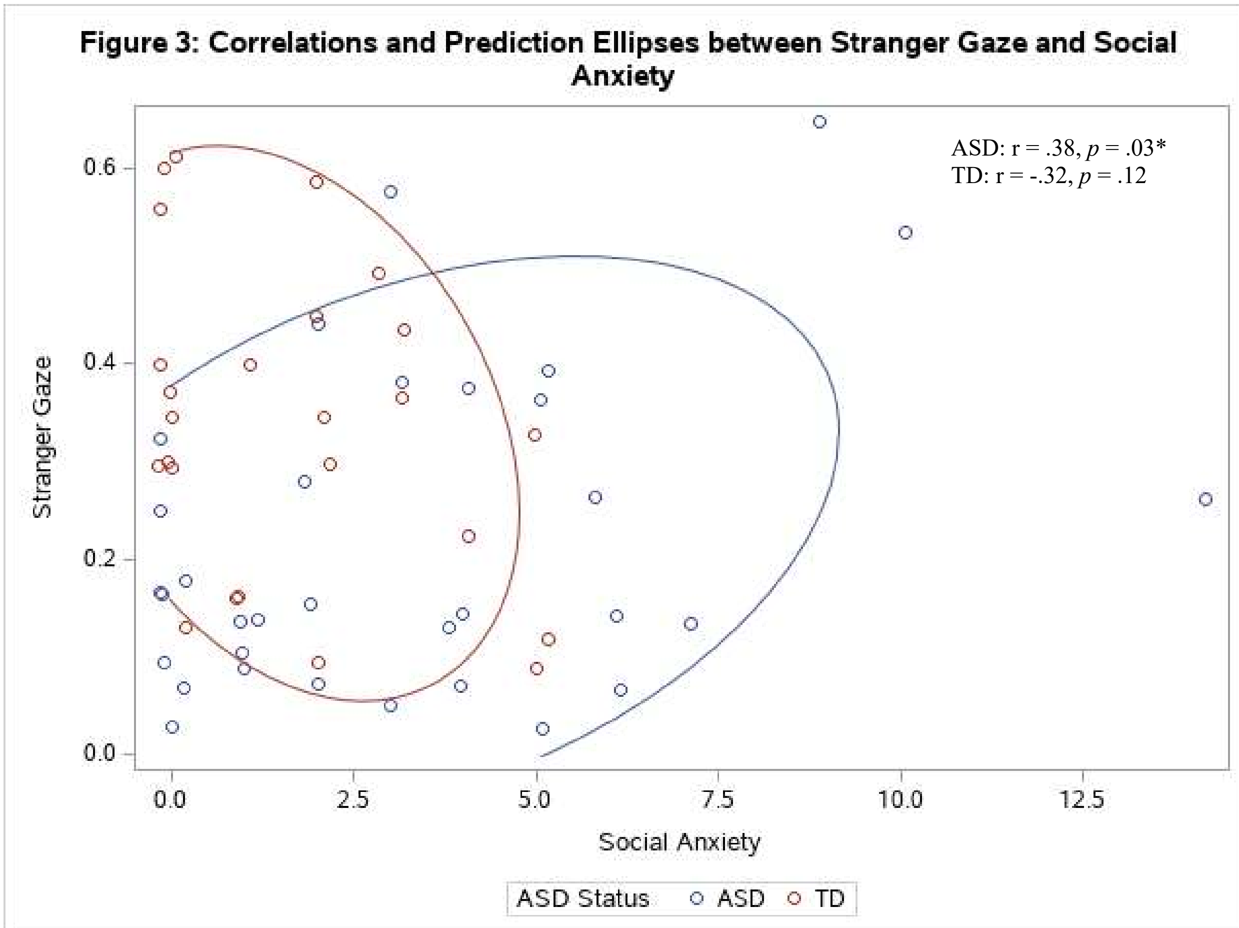

Figure 3. Scatterplots and 75% prediction ellipses to visualize correlations between Stranger Gaze and social anxiety.

Stranger Gaze

The correlations between time looking at the stranger and ADOS scores were insignificant for both the ASD and TD groups. The ASD group exhibited a significant positive correlation (r = .38) between time looking at the stranger and Spence Social Anxiety raw scores (p = .03). In contrast, the opposite pattern was observed through a negative correlation (r = -.32) in the TD group, though this relationship was not statistically significant (p = 0.12). Similar patterns were also identified when comparing stranger gaze to Spence Generalized Anxiety raw scores. The ASD group demonstrated a significant positive correlation (r = .35, *p* = .043), while the TD group displayed a negative correlation (r = -.24, *p* = .26). Significant correlations between stranger gaze and Total Anxiety raw scores were observed in both the ASD and TD groups. While the ASD group revealed a significant positive relationship between time spent looking at the stranger and Total Anxiety (r = .52, *p* = .0014), the TD group demonstrated a significantly negative relationship (r = -.40, *p* = .0496).

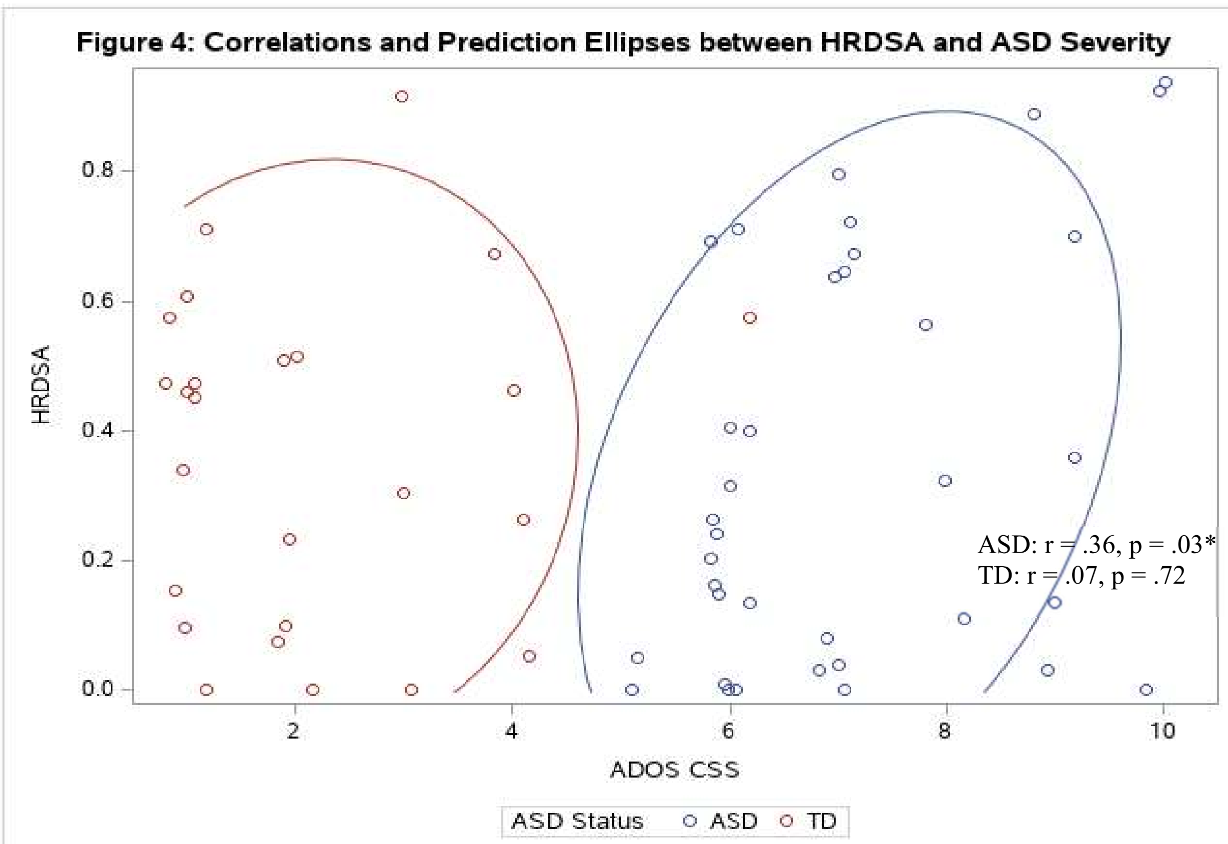

Figure 4. Scatterplots and 75% prediction ellipses to visualize correlations between HRDSA and ASD severity.

HRDSA

A significant positive correlation between time spent in HRDSA and ADOS scores was observed in the ASD group (r = .36, *p* = .0312), though no relationship was observed in the TD group. A near-significant negative correlation was found between HRDSA and Spence Generalized Anxiety raw scores in the ASD group (r = -32, *p* = .07), though all other correlations between HRDSA and Anxiety variables were insignificant.

HRDSA Depth

Positive correlations between HRDSA Depth and ADOS scores were found in both the ASD and TD groups. This relationship was significant for the ASD group (r = 0.43, *p* = .0157) but not the TD group (r = .36, *p* = .097). No significant correlations were found between HRDSA depth and Spence Anxiety variables in either groups.

Correlations with additional Attentional Variables

Table 5: Correlations with additional Attentional Variables

	ASD Severity		**Social Anxiety**	
	ASD	**TD**	**ASD**	**TD**
	r (p)	**r (p)**	**r (p)**	**r (p)**
Total Looks	-.27 (.11)	.03 (.89)	.36 (.04)*	-.16 (.45)
Median Duration	-.18 (.30)	-.11 (.60)	.13 (.46)	-.10 (.63)

Table 5. Results from Pearson correlations between additional attention variables (total number of looks and median look duration) and ASD severity and anxiety. Correlation coefficients (r) and p-values (*p*) are included, grouped by ASD status.

No significant correlations were found between ASD severity and the total number of looks toward the stranger or the median duration of these looks. A significant positive correlation ($r = .36$, $p = .04$) was found between social anxiety and the total number of looks to the stranger in the ASD group, though not in the TD group. No significant correlations were found in relation to the median duration of looks to the stranger.

Discussion

The primary goal of this study was to characterize attentional patterns (both visual and physiological) during the Stranger Approach task in children with ASD. Our results showed that young children with ASD exhibited reduced gaze towards the stranger in comparison to TD controls. Interestingly, this pattern was not seen with the physiological measure of attention as both groups spent nearly the same amount of time in HRDSA. Notably, time spent in visual attention and HRDSA were very similar in the TD group, but inconsistent in the ASD group. This brings up two important questions: (1) why are children with ASD spending less time looking at the stranger? and (2) why do visual and physiological measures of attention yield different results for children with ASD? To answer these questions, we consider previous literature and supplemental analyses with anxiety and ASD symptomatology.

The Stranger Approach task is remarkable in that it presents a social situation through the presence of a novel person that may be perceived as a threat. Thus, there are multiple explanations for the demonstrated reduced stranger gaze that must be considered. Could this be a product of overall reduced social attention that has been seen in previous literature, or is anxiety-induced threat bias playing a role? Many studies have found that elevated anxiety results in increased orienting and delayed disengagement towards threats in TD populations (Abend et al., 2018; Koster et al., 2006), but this finding is inconsistent in ASD groups (Hollocks et al., 2013;

May et al., 2015; Milosavljevic et al., 2017). Interestingly, our results indicated a conflicting pattern with a significant positive correlation between stranger gaze and social anxiety in the ASD group, but not the TD group. To evaluate this finding in the context of threat bias, we examined the total number of looks and the duration of these looks in both groups. In the ASD group, there was not a significant correlation between anxiety and the median duration of looks to the stranger, though there was a significant positive correlation with the total number of looks to the stranger ($r = .36$, $p = .04$). Since the stranger did not attempt to gain the participant's attention at any time and the experiment took place in a static environment, stranger gaze may be interpreted as deliberate execution of attention rather than social orienting. We must also consider that we are not certain how each child perceived the stranger, as the stranger may have been seen as a threat, opportunity for social interaction, both, or neither. Therefore, we are hesitant to claim that social anxiety induced a threat bias, but rather a broader attentional bias towards the stranger that is worth investigating further. Since the ASD group spent significantly less time looking at the stranger despite a positive correlation with anxiety measures, this leads us to attribute the reduced gaze to overarching patterns of reduced social attention in ASD.

Based on previous literature demonstrating positive threat bias in TD children with social anxiety, we expected social anxiety to be associated with increased stranger gaze in the TD group. Interestingly, we observed the opposite trend. Though not statistically significant ($p = .12$), the TD group exhibited a negative correlation between social anxiety and stranger gaze. As social anxiety was not correlated to typical indicators of threat bias (i.e., number of looks and duration of looks), these results conflict with previous literature. One explanation may be that for this age group, the stranger was not perceived as a threat by TD children. In this case, the Stranger Approach task would represent a primarily social situation and reduced gaze would be consistent with findings that social anxious individuals avoid maintaining eye contact. Another factor that may explain why our results differ from previous literature is the naturalistic environment in which the Stranger Approach task took place. A recent study comparing experimental conditions found social anxiety to be associated with reduced social gaze in a real-life setting, but not during video tasks in a laboratory (Rubo et al., 2019). As previous studies of social anxiety and attentional bias tend to take place in controlled laboratory settings using computerized stimuli, this may explain the divergent results of the present study.

Another important finding of this study was the insignificant correlations between the attentional measures, eye gaze and HRDSA. Though HRSDA is well-established as an attentional measure for infants (Reynolds & Richards, 2008; Tonnsen et al., 2018), this finding has yet to be explored in young children. If HRDSA was accurately indexing attention, we would expect to see a positive correlation with stranger gaze, as observed visual attention is the prominent and standard measure of attention in young populations. However, our results showed no significant correlations in either the ASD or TD groups. Thus, the results from this study do not support the notion that HRDSA may be used in place of visual measures to quantify attention in young children.

Though HRDSA did not cleanly map onto visual attention, our results still bring to question why the attentional measures yielded differing results in the ASD group, but not the TD group. One possible explanation is the relationships between these measures and ASD severity. In the ASD group, our study found that overall ADOS CSS scores were significantly positively correlated to HRDSA ($r = .36$, $p = .03$) and, although not significant, negatively correlated to stranger gaze ($r = -.28$, $p = .10$). Greater degrees of reduced stranger gaze in children with more severe symptoms are consistent with findings that reduced eye contact and gaze monitoring are core features of ASD. It is important to note that the correlation between ASD severity and HRDSA was unexpected, especially since there are no ASD studies, that we are aware of, that utilize HRDSA for this age group. With that in mind, ADOS scores were the only variable in this study (besides HRDSA depth) that was significantly associated with HRDSA, which leads us to believe that HRDSA can provide meaningful, complimentary information to better our understanding of how physiological and cognitive processes are affected by ASD symptomology. Further investigation into these associations is needed to address opposing patterns of eye gaze and HRDSA in children with ASD.

Limitations

There are important limitations to consider when interpreting the results of this study. First, age and IQ were not matched between the ASD and TD groups. Though the mean ages between groups were nearly identical, Mullen ELC scores were significantly different. It should be noted that many researchers argue that IQ is not a covariate in studies of neurodevelopmental disorders (Dennis et al., 2009), so having unmatched groups is acceptable practice. Additionally, participants in our samples were predominantly male. These demographic limitations restrict the generalizability of our findings within the young ASD population. Furthermore, some data, such as the SPAS, was not available for all participants, and thus may be a source of bias in our supplemental analyses.

Considering the crucial role that anxiety is hypothesized to play in physiological regulation and attention, it would have been ideal to split the ASD group into two groups: one with anxiety and one without. Because the present study only had one ASD group, there were varying levels of anxiety within this group, and we had to rely on correlations for these analyses.

This limited our ability to distinguish between the roles of ASD severity, anxiety, and the interaction between these variables in modulating attention.

Conclusions and Future Directions

The present study builds upon visual and physiological profiles of attention in children with ASD. Our results suggest that while children with ASD exhibit reduced gaze behaviors in a social and potentially fearful situation, they demonstrate similar patterns of HRDSA in comparison to TD controls. A notable finding of this study was a broad, anxiety-induced attentional bias towards the stranger in the ASD group. While we cannot claim this to be a product of threat bias, we did find a significant positive correlation between social anxiety and stranger gaze, which is opposite the trend we identified in the TD group. This supports the notion that the role of anxiety in attention may present differently in ASD, warranting further study into these processes. A significant outcome of this study was the assessment of HRDSA as a measure of attention in preschool-aged children with ASD. While HRDSA did not clearly map onto gaze behavior, the significant correlation between HRDSA and ASD symptomology highlights the complex physiological nature of the disorder and calls for continued study of physiological attention in young ASD populations. Future research into the relationships between anxiety, attention, and physiology in ASD will help us better understand the underlying mechanisms and implications of this disorder, guiding early intervention and screening efforts to improve developmental outcomes.

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