VISUAL ATTENTION COMPOSITES ACROSS THE EARLY DEVELOPMENT OF INFANTS AT HEIGHTENED GENETIC RISK FOR AUTISM SPECTRUM DISORDER

by

Lisa Sperle

Bachelor of Science, University of Texas at Austin, 2010

Master of Science, University of Pittsburgh, 2014

Submitted to the Graduate Faculty of

the Dietrich School of Arts and Sciences

in partial fulfillment

of the requirements for the degree of

Doctor of Philosophy

University of Pittsburgh

2018

UNIVERSITY OF PITTSBURGH

THE DIETRICH SCHOOL OF ARTS AND SCIENCES

This dissertation was presented

by

Lisa Sperle

It was defended on

July 18, 2017

and approved by

Carla Mazefsky, Ph.D., Associate Professor, Department of Psychiatry

Michael Pogue-Geile, Ph.D., Professor, Department of Psychology

Jennifer Silk, Ph.D., Associate Professor, Department of Psychology

Diane L. Williams, Ph.D., Professor, Department of Communication Sciences & Disorders, The Pennsylvania State University

Dissertation Chair: Mark S. Strauss, Ph.D., Associate Professor, Department of Psychology

Copyright © by Lisa Sperle

2018

Mark S. Strauss, Ph.D.

VISUAL ATTENTION COMPOSITES ACROSS THE EARLY DEVELOPMENT OF INFANTS AT HEIGHTENED GENETIC RISK FOR AUTISM SPECTRUM DISORDER

Lisa Sperle, Ph.D.

University of Pittsburgh, 2018

Aggregating attentional measures across diverse visual stimuli into composite scores quantifies how infants generally attend to their environment. These measures, called visual attention composites, show high clinical utility in the infant literature for identifying risk populations, such as preterm infants and those at risk for intellectual disability, as well as for predicting later childhood intellectual functioning. There is also recent evidence that visual attention composites from various eye-tracking tasks have high clinical utility for identifying children with autism spectrum disorder (ASD; Frazier et al., 2016). Thus, the present study is the first to date to explore the application of visual attention composites to infants with and without heightened genetic risk for ASD. Participants consisted of 47 infant siblings of children with ASD (high-risk infants; HR) and 39 infant siblings of typically developing children (low-risk infants; LR). Infants were given follow-up assessments at 24, 36 and/or 48 months and classified as ASD, non-typically developing (if non-ASD developmental delays were present) or typically-developing. Eye-tracking data was collected while infant participants viewed a diverse array of stimuli, including static faces, dot patterns, objects and dynamic videos at 11 and 16 months of age. Results indicated that visual attention composites calculated from these eye-tracking tasks were predictive of later childhood atypical development and ASD diagnosis. Furthermore, 16-month attentional composites related to the ratio of attention to figures versus background were predictive of 36-month intellectual functioning. Collectively, findings support visual attention composites as predictors of later development and highlight the potential benefit of creating a visual attention clinical battery to improve early ASD diagnostics. Further clinical implications and advantages of incorporating attentional measures in infant testing are discussed.

TABLE OF CONTENTS

LIST OF TABLES .... **ix**

LIST OF FIGURES .... **xi**

1.0 INTRODUCTION **1**

1.1 VISUAL ATTENTION IN EARLY TYPICAL DEVELOPMENT **4**

1.2 VISUAL ATTENTION IN THE EARLY DEVELOPMENT OF CLINICAL (NON-ASD) POPULATIONS **14**

1.3 VISUAL ATTENTION IN THE DEVELOPMENT OF ASD **20**

1.4 THE PRESENT STUDY **27**

2.0 METHODS **29**

2.1 PARTICIPANTS **29**

2.2 PROCEDURE **31**

2.3 DATA REDUCTION AND ANALYSIS **36**

3.0 RESULTS **40**

3.1 DATA SCREENING OF *A PRIORI* ATTENTIONAL COMPOSITES **40**

3.2 PRINCIPAL-COMPONENTS ANALYSIS OF *A PRIORI* VISUAL ATTENTION COMPOSITES **40**

3.3 DATA SCREENING OF *DATA-DRIVEN* ATTENTIONAL COMPOSITES 42

3.4 INTERCORRELATIONS AMONG VISUAL ATTENTION COMPOSITES 43

3.5 VISUAL ATTENTION ACROSS 11 AND 16 MONTHS BASED ON RISK STATUS 44

3.6 ATTENTIONAL COMPOSITES AS PREDICTORS OF ATYPICAL DEVELOPMENT AND ASD DIAGNOSIS 48

3.7 INFANT ATTENTIONAL COMPOSITES AS PREDICTORS OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS 59

3.8 INFANT DEVELOPMENTAL QUOTIENTS AS PREDICTOR OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS 64

4.0 DISCUSSION 67

4.1 VISUAL ATTENTION ACROSS 11 AND 16 MONTHS 68

4.2 ATTENTIONAL COMPOSITES AS PREDICTORS OF ATYPICAL DEVELOPMENT AND ASD DIAGNOSIS 73

4.3 INFANT MEASURES AS PREDICTORS OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS 79

4.4 CLINICAL IMPLICATIONS 81

4.5 LIMITATIONS 83

4.6 FUTURE DIRECTIONS 84

4.7 CONCLUSIONS 85

5.0 TABLES **87**

6.0 FIGURES **119**

7.0 BIBLIOGRAPHY **133**

LIST OF TABLES

Table 1. Participant Characteristics across Infancy based on Genetic Risk Status 87

Table 2. Diagnostic Classification Criteria for Infant Participants at 24, 36 and/or 48 Months of Age. 89

Table 3. Participant characteristics by outcome classification. 91

Table 4. Operational Definitions for Calculating *A Priori* Visual Attention Composite Scores.. 93

Table 5. Extreme Outlier Frequencies of *A Priori* Attentional Composites Across 11 and 16 Months by Risk Group.. 96

Table 6. Summary of Principal-Components Analyses of Eye-Tracking Tasks 97

Table 7. Extreme Outlier Frequencies of *Data-Driven* Attentional Composites Across 11 and 16 Months by Risk Group.. 98

Table 8. Pearson Correlations for *A Priori* Visual Attention Composite Scores at 11 Months ... 99

Table 9. Pearson Correlations for *A Priori* Visual Attention Composite Scores at 16 Months . 100

Table 10. Pearson Correlations for *Data-Driven* Visual Attention Composite Scores at 11 Months 101

Table 11. Pearson Correlations for *Data-Driven* Visual Attention Composite Scores at 16 Months 103

Table 12. Descriptive Data for Visual Attention Composite Scores by Genetic Risk across Infancy 105

Table 13. Results of 2x2 (Age x Risk Status) Repeated Measures Analysis of Variance 107

Table 14. Descriptive Data for Visual Attention Composite Scores at 11 Months by Outcome Group 109

Table 15. Descriptive Data for Visual Attention Composite Scores at 16 Months by Outcome Group 111

Table 16. *A Priori* and *Data-Driven* Predictors Considered for Binary Logistic Regression Analyses 113

Table 17. Logistic Regression Results of Predicting Atypical Development or ASD Diagnosis from 11 Months 114

Table 18. Logistic Regression Results of Predicting Atypical Development or ASD Diagnosis from 16 Months 116

Table 19. Beta Weights for Multiple Linear Regression Results of Predicting 36-Month Mullen DQ from 11- and 16-Month Data 118

LIST OF FIGURES

Figure 1. Six example stimuli used for visual attention composites of autism risk index 119

Figure 2. Developmental changes in infant look duration 120

Figure 3. Model of attention phases measured by heart rate 121

Figure 4. Example emotion face stimulus 122

Figure 5. Example attractiveness face stimulus 123

Figure 6. Example test trial from face prototype task 124

Figure 7. Example test trial from dot prototype task 125

Figure 8. Example face memory stimulus 126

Figure 9. Example object memory stimulus 127

Figure 10. Still frame image from dynamic MR2 video 128

Figure 11. Example stimulus with designated regions of interest (ROI) 129

Figure 12. Risk status by age (in months) on active scanning composite score 130

Figure 13. Risk status by age on figure vs. background attentional composite score for static tasks 131

Figure 14. Boxplot of ASD infants' Mullen Developmental Quotient (DQ) at 36 months 132

1.0 INTRODUCTION

This study is focused on developing visual attention composites as a way of assessing individual attentional differences among preverbal infants. This composite represents a quantification of looking behavior aggregated from multiple individual tasks. A visual attention composite score quantifies looking behavior on a more global level than individual task performance and measures how participants generally attend to their environment across diverse stimuli. It is suggested that the creation of visual attention composites may be beneficial in reducing the high variability typically seen in measures of infant attention, which are influenced by various moment-to-moment factors during individual tasks, such as stimulus complexity, stimulus type (e.g., static or dynamic) and infant mood.

Rather than using individual tasks, the typical infant development literature consistently shows visual attention composites from infancy to be a stronger predictor of later childhood cognitive functioning than standardized infant cognitive tests (for meta-analysis, see McCall & Carriger, 1993). These relationships between infant attentional composite scores and childhood intellectual functioning have also been replicated in clinical populations, such as preterm infants (e.g., Rose, 1983), cocaine-exposed infants (e.g., Singer et al., 1999) and infants at risk for intellectual disability (e.g., Fagan, Singer, Montie, & Shepherd, 1986). Furthermore, recent evidence suggests that the creation of visual attention composites from diverse eye-tracking tasks yields high predictive value in the identification of children with autism spectrum disorder (ASD; Frazier et al., 2016). Thus, the present study explored the application of visual attention composites to understanding the early development of infants at heightened genetic risk for autism spectrum disorder (ASD).

ASD is a neurodevelopmental disorder characterized by impairments in social communication and interaction as well as the presence of restricted, repetitive behaviors, interests and/or activities (APA, 2013). Current CDC estimates a prevalence rate of 1 in 68 children having been diagnosed with ASD with the diagnosis 4.5 times more common among males than females (Christensen et al., 2016). Since children younger than two years of age cannot be reliably diagnosed with ASD (Kleinman et al., 2008), there has been a strong recent interest in the field of autism in assessing infants who have an older sibling diagnosed with ASD (also known as infant-siblings) to help understand the origins of ASD. Typically, these genetically high-risk (HR) infants are compared to infants characterized as low risk (LR) because their older siblings do not have ASD. Up to 20% of HR infants will later receive an ASD diagnosis according to current estimations (Ozonoff et al., 2011). Although the majority of HR infants will not receive an ASD diagnosis, research also indicates that HR infants tend to share many traits with diagnosed individuals due to genetic transmission of autism-like traits. For example, HR infants may have higher rates of delays and problems in areas of development like language and motor skills compared to LR peers (for review, see Rogers, 2009). Hence, studying infant-siblings may be beneficial to scientific understanding of the early origins and markers of ASD but also of variable or atypical infant development.

Thus, for this study, eye-tracking data was collected while infants viewed diverse static and dynamic stimuli. Visual attention composite scores from these eye-tracking tasks were calculated to obtain general attentional profiles of HR and LR infants. The present study had four aims. The first aim was to investigate group differences in infants' visual attention across 11 and

16 months of age based on infant genetic risk status (HR vs. LR). The second aim was to explore infant attentional composites at 11 and 16 months of age as predictors of later childhood outcome classifications (e.g., ASD and non-typically (NT) developing). NT children are characterized by global developmental delays, language delays and/or social functioning concerns. The third aim was to examine relationships between visual attention composites and later childhood cognitive/developmental functioning across infancy. Lastly, the fourth aim of this research was to assess the predictive value of visual attention composites for later functioning relative to collected standardized infant measurement.

A large extant literature on ASD supports that there are visual attention differences and/or deficits across the lifespan, including infants and young children with ASD (Chawarska, Volkmar, & Klin, 2010; Elison, Sasson, Turner-Brown, Dichter, & Bodfish, 2012; Frazier et al., 2016; Landry & Bryson, 2004; Sasson, Elison, Turner-Brown, Dichter, & Bodfish, 2011; Swettenham et al., 1998; Zwaigenbaum, Bryson, Rogers, Roberts, Brian, & Szatmari, 2005).

As an empirical foundation for the present study, the following literatures are reviewed: (a) visual attention in early typical development, (b) visual attention in the early development of clinical (non-ASD) populations, and (c) visual attention in the development of ASD. Collectively, these literatures support the present study's assessment of an infant-sibling sample using a novel approach of developing attentional composite measures derived from multiple tasks in order to understand possible early differences in the development of attention.

1.1 VISUAL ATTENTION IN EARLY TYPICAL DEVELOPMENT

Conceptual overview of visual attention. It is argued that "attention is a core component of adaptive responsiveness to the environment" and involves several component processes of attention: orienting, selection, maintenance and disengagement (Reynolds, Courage, & Richards, 2013). Many developmental studies have utilized various aspects of infant looking behavior as a measure of attention and cognitive processing. In developmental psychology infancy research, three fundamental phenomena of looking behavior include preferential looking to faces, a systematic decline in looking with repeated presentation of a stimulus (e.g., habituation; Fantz, 1964) and greater attention (e.g., higher proportion of looking) to a novel stimulus compared to a familiarized stimulus as presented in a paired-comparison task (Fagan, 1990).

Early visual attention preferences. Newborn infants are more responsive to facial representations than equally complex non-social stimuli (Cassia, Turati, & Simion, 2004; Goren, Sarty & Wu, 1975; Johnson & Morton, 1991). This heightened response to faces was shown by infants' turning and following faces more than stimuli that had the same components as a face but were scrambled (Goren et al., 1975). This suggests that newborn infants demonstrate an attentional preference for faces in comparison to equally complex, non-social stimuli (Goren et al., 1975; Johnson & Morton, 1991; Cassia et al., 2004). An attentional preference for social stimuli, particularly for faces, persists beyond two months of age as well (Courage, Reynolds, & Richards, 2006; Johnson, Dziurawiec, Bartrip, & Morton, 1992; Turati, Valenza Leo, & Simion, 2005). For example, three month-old infants display an attentional bias to faces over non-face patterns, as illustrated by the greater proportion of time spent looking to the faces compared to non-face patterns (Turati et al., 2005). This enhanced attention to faces continues from 14 weeks to 12 months of age with infants' look durations to faces increasing in a quadratic fashion with age, whereas look durations to achromatic geometric patterns decrease linearly with age (Courage et al., 2006). Furthermore, this attentional preference for social stimuli is also illustrated by these infants showing sustained attention for a larger proportion of time when presented with faces or dynamic social interactions from *Sesame Street* compared to achromatic geometric patterns (Courage et al., 2006).

Developmental course of visual attention. A review of the visual attention literature supports three phases of look duration across the first year of life (Colombo, 2001; Colombo, 2002; Colombo, Harlan, & Mitchell, 1999; Courage, Reynolds, & Richards, 2006; Reynolds et al., 2013). This tri-phasic model is depicted in Figure 2 (Colombo, 2002). From birth to 2 or 3 months of age, look duration increases, followed by a decrease in look duration from 3 to 5 or 6 months of age, after which look duration plateaus or may gradually increase (Colombo et al., 1999). As newborns, a *reflexive system* controls visual attention (Reynolds et al., 2013). Due to fairly immature visuo-motor abilities, young infants have limited scanning abilities (Aslin, 1987) and demonstrate difficulties disengaging from a stimulus after visually fixating on it, particularly from 1-2 months of age. This well-established developmental phenomenon is known as obligatory looking or "sticky attention" (Hood, 1995). Colombo (2001) posited that this initial increase of attention from birth to 10 weeks of age might be indicative of developments in arousal and alertness as mediated by pathways linking the arousal system in the brain stem with the cerebral cortex. Furthermore, neurological development involving the retina and visual pathways to the cortex occurs rapidly between two and three months of age. This development is accompanied by the following significant gains in visual functioning: "an expansion of the effective visual field, moderation of inhibitory mechanisms that restrict eye movements, and the onset of more mature perceptual abilities whereby infants come to recognize objects and to determine their spatial layout" (Reynolds et al., 2013). Broadly, infants gain greater voluntary control over their visual attention by 3 months of age (Colombo, 2001).

It follows that a developmental decline occurs in infant look duration from this early reflexive system during the 3-6 month of age period, coinciding with continuing improvements in voluntary control over attention. It is believed that a cortical *posterior orienting system* emerges during this developmental phase (Rothbart, Posner, & Boylan, 1990). The posterior orienting system involves a spatial orienting network that can voluntarily direct attention to peripheral stimuli, which may be salient locations in the environment (Reynolds et al., 2013). Consequently, infants demonstrate less sticky attention and gain greater voluntary abilities to shift attention to salient stimuli. Within the posterior orienting system, an object recognition network also emerges to detect object features (like color and form) and allow for identification of "what" an object is. Therefore, with gains in voluntary control of attention, look duration shows a decline from 3 to 6 months of age. In other words, 3 to 4-month-old infants look longer at stimuli compared to older infants aged 7-8 months (Colombo & Mitchell, 1990), which is theorized to reflect developing disengagement abilities (Colombo, 2002) and more efficient processing (Reynolds et al., 2013).

Look duration in the last stage (after 6 months of age) generally shows a plateau that reflects voluntary, task-driven attentional abilities (Colombo, 2002) and characterizes the predominance of the cortical *anterior attention system* (Reynolds et al., 2013). This is evidenced by differences in infant looking behavior based on stimulus characteristics like complexity and motion. For example, Courage and colleagues (2006) found that infants after 6 months of age attended longer to the more complex images of faces and Sesame Street compared to achromatic patterns. Their results also indicated that these infants looked longer at dynamic stimuli compared to static stimuli. Similarly, Ruff and Saltarelli (1993) found a decrease in infants' attention to simple objects, whereas attention to more complex objects increased. Collectively, these findings support that infants gain greater abilities to modulate their attention based on the specifics of the task. Infants attend briefly and disengage attention after efficient information processing, whereas infants use sustained attention to stimuli (e.g., complex and/or dynamic stimuli) that need further processing (Reynolds et al., 2013).

Advancements in visual attention continue through early childhood in correspondence with developmental changes in the prefrontal cortex. Furthermore, Reynolds and colleagues (2013) posited that the development of sustained attention is critical for more sophisticated cognitive processes and behaviors, including but not limited to language, self-regulation and mental representation abilities. In summary, infancy is characterized by three phases of attention that correspond with early developments in voluntary control, disengagement, and arousal systems.

Individual differences in looking behavior. Across early development, research indicates heterogeneity in look duration with moderately stable individual differences from multiple attentional assessments *within* age categories (Colombo, Mitchell, O'Brien, & Horowitz, 1987). When presented with visual recognition tasks with limited presentation times, infants with "prolonged looking" attentional profiles showed poorer visual recognition performance than their shorter looking peers. This result led prolonged looking durations to be interpreted as infants demonstrating slower processing (Colombo, Mitchell, Coldren, & Freeseman, 1991). "Prolonged looking" infants demonstrate difficulties inhibiting or disengaging attention from visual stimuli (Frick, Colombo, & Saxon, 1999; Hood, 1995; Jankowski & Rose, 1997). For example, infants with prolonged looking showed significantly fewer scanning movements across the visual stimuli than shorter-looking peers (Jankowski & Rose, 1997). There is also evidence that look duration and disengagement are related on a continuum. Frick and colleagues (1999) demonstrated a fairly strong correlation (r = .62) between the length of time to initiate eye movements during disengagement trials to overall look durations to a different set of visual stimuli in 3-4 month-olds. Moreover, this association between the initiation of eye movements and look durations was specific only to trials in which disengagement was required (e.g., the central stimulus remained on-screen during the presentation of a peripheral visual target). Broadly, these findings further support that infants' look duration is reflected in large part by early abilities to inhibit or disengage attention.

In regard to difficulties disengaging attention, research indicates that infants with "prolonged looking" attentional profiles perseverate on local stimuli features rather than first attending to the global configuration as do children and adults (Colombo & Janowsky, 1998). However, by manipulating a red light to entice "prolonged looking" 5-month-old infants to shift attention across various areas of stimuli, previous visual recognition performance deficits were mitigated, suggesting that infant attention is malleable and can have beneficial effects for cognitive performance (Jankowski, Rose, & Feldman, 2001).

Predictive value of looking behavior. Studies show negative correlations between look duration and later childhood intellectual performance, such that prolonged looking is associated with poorer cognitive functioning as measured by standardized IQ tests (Bornstein & Sigman, 1986; Colombo, 1993; Colombo & Mitchell, 1990; Colombo, Mitchell, & Horowitz, 1988; Colombo et al., 1991; Colombo, Shaddy, Richman, Maikranz, & Blaga, 2004; McCall & Carriger, 1993; Rose, Feldman, & Jankowski, 2004; Rose, Feldman, & Jankowski, 2012; Rose, Slater, & Perry, 1986; Sigman, Cohen, Beckwith & Parmalee, 1986; Tamis-LeMonda & Bornstein, 1989). Across habituation and recognition memory paradigms, McCall and Carriger's (1993) meta-analysis demonstrated that the median long-term predictive correlation of infant looking measures within the first year of life to later IQ scores of children between one and eight years of age is approximately 0.45.

One of these well-established paradigms with high predictive utility is the Fagan Test of Infant Intelligence (FTII; Fagan & Detterman, 1992), a standardized paired comparison test involving a series of 10 different tasks or novelty "problems." Stimuli consist of grayscale and colored photographs of infant faces, adult male faces and adult female faces. Infants were familiarized to an identical stimulus presented on both the left and right positions, followed by a test phase in which this familiar stimulus was paired simultaneously with a novel stimulus. Attention to novelty was quantified as the mean percentage of attention to novel images when paired next to a previously shown familiar stimulus across all 10 tasks. Performance characterized as at-risk for childhood developmental delay is defined by a novelty score ≤ 53% (Rose & Orlian, 2001). Studies indicate that correlations *between* novelty scores on different problems are quite low (Rose & Feldman, 1987; Rose et al., 2004), which may reflect the influence of a multitude of moment-to-moment factors during a single task, such as infant mood, stimulus type (e.g., static, dynamic), and stimulus complexity (e.g., simple shapes, faces). Therefore, creating attentional composite scores may minimize the effect of these moment-to-moment factors. Research using the FTII indicates that infants' attention to novelty composited across tasks at 7 months of age is significantly related to intellectual functioning (as measured by IQ tests) at three and five years of age, with impressively consistent correlations at both age points (r = .42; Fagan, 1984). Although the majority of studies across stimuli, paradigms and research labs have found strong correlations between infant looking behavior and later functioning, there is some evidence for lesser predictive value. One longitudinal study of infants tested monthly (from 3-9 months of age) measuring both infant look durations and attention to novelty yielded correlations ranging in magnitude from .17 to .22 to follow-up assessment scores at 24 months (Colombo et al., 2004). The authors note that their correlations are somewhat lower than most of the extant literature (Colombo et al., 2004; Bornstein & Sigman, 1986; McCall & Carriger, 1993), which may be due to their emphasis on language development in their selection of outcome measures at their 24-month assessments.

Importantly, this area of research indicates that infants' greater attention to novelty during visual recognition memory tasks is predictive of higher cognitive function, whereas standardized infant measures (like concurrent Bayley Mental Development Index; MDI) fail to be predictive of later intellectual functioning (Bornstein & Sigman, 1986; McCall & Carriger, 1993; Rose & Feldman, 2000). Non-risk infant samples show correlations between standardized infant development tests (by 6 months of age) and IQ scores (at 5-7 years) with a median value of .09 across studies (Kopp & McCall, 1982; McCall & Carriger, 1993). Even when standardized infant development tests hold predictive value, longitudinal studies suggest that the predictive value tends to decline with later outcome ages (McCall, 1979; McCall & Carriger, 1993). In contrast, McCall and Carriger (1993) posit that it is unusual in the longitudinal literature that correlations between infant visual attention and later IQ remain quite persistently high across childhood ages. Thus, the predictive utility of early visual attention composites is supported across looking paradigms and stimuli, tends to outperform standardized infant development measures and uniquely remains highly predictive across later outcome ages.

Attention and heart rate. Although visual attention measured by look duration and attention to novelty has been strongly emphasized, it has also been proposed that attention serves an arousal function, commonly known as "attention as state" (Ruff & Rothbart, 1996). They posit that changes in attention can modulate arousal or overall attentiveness levels for peak performance and learning (Richards, Reynolds, & Courage, 2010). According to a *general arousal/attention system* framework, this system is influential across early development with increasing time spent in this arousal state as infants age (Richards, 2001, 2010; Richards & Cronise, 2000; Richards et al., 2010). As brain systems related to arousal develop, the ability to selectively engage with a stimulus in the environment (known as sustained or focused attention) increases over early infancy from only 5-10 seconds in 3-month-olds to a few minutes or more by toddlerhood (Reynolds & Richards, 2007; Ruff & Capozzolli, 2003). In addition to looking behavior, infant heart rate (HR) is a well-established psychophysiological measure for assessing when infants are actively engaged during visual attention to a stimulus (Richards & Casey, 1990). As depicted in Figure 3, after initial orienting to a stimulus, sustained attention is accompanied by a deceleration in heart rate (Richards & Casey, 1990, 1991, 1992).

Possible mechanisms for the predictive value of infant looking behavior for childhood IQ. To explain the robust long-term relationships between infant looking behavior and later intellectual functioning in childhood, researchers have implicated the role of various mechanisms, including individual differences in attentional disengagement, processing speed, information processing strategy and short-term memory (Colombo, 1993; Colombo, 2002; Colombo, Freeseman, Coldren, & Frick, 1995; Colombo, Richman, Shaddy, Greenhoot, & Maikranz, 2001; Fagan, 1984). For example, given the associations between look duration and disengagement ability, Colombo (2002) argued that "prolonged looking" infants spend more time in the attention termination phase during which infants are looking but not actively engaged (as evidenced by HR deceleration). Indeed, results indicate that prolonged lookers spend proportionately more time in attention termination than shorter lookers and suggest that prolonged looking may be indicative of difficulties with attentional disengagement (Colombo et al., 2001). After attentiveness has dwindled, prolonged lookers are more likely to remain visually fixated on a stimulus, whereas short lookers are more likely to shift their visual fixation away from the stimulus (Reynolds et al., 2013). Therefore, prolonged time spent in the attention termination phase may therefore help explain the relationship between longer look duration and poorer visual recognition performance (Colombo, 2002).

There is also empirical support for important differences between “prolonged looking” infants and short lookers in processing speed and the use of global versus local information processing strategies. Colombo and colleagues (2001) examined 4 month-old infants’ processing speed and processing strategy during a paired-comparison task by manipulating the length of familiarization time to visual stimuli and systematically varying stimuli similarities based on global or local properties, respectively. During the short 20s familiarization time, short lookers showed an attentional preference (evidenced by longer looking) to stimuli based on global characteristics, whereas prolonged lookers did not show any looking preference. When familiarization time was increased to 30s, short-looking infants shifted from attentional preferences for global property differences to local property differences, but prolonged lookers continued failing to show an attentional preference. Only prolonged lookers required additional familiarization (50s) to show an attentional preference, but even so, they demonstrated an attentional preference for differences in local stimuli characteristics. Prolonged looking infants did not demonstrate an attentional preference for global property differences under any experimental conditions. These findings support an initial global processing strategy for short lookers, whereas prolonged lookers are less efficient processers by utilizing a local processing strategy initially and generally processing information more slowly. Lastly, it is evident that attention and recognition memory are tightly linked (Reynolds, 2015; Rose et al., 2004), such that visual attention differences may reflect individual differences in infants' short-term memory abilities. Therefore, individual differences in short-term memory may affect *when* and *where* infants distribute their attention to visual stimuli (Fagan, 1972; Fagan, 1984; Kwon, Luck, & Oakes, 2014). This underlying memory construct measured in infant looking tasks may thus parallel performance during standardized IQ tests, since subtasks like digit span often capture short-term memory abilities (Cohen & Gowen, 1978).

Summary. From early infancy, a large literature supports an attentional preference for social stimuli, such as faces. Simultaneously, developmental shifts are occurring in visual attention across the first year of life. According to the tri-phasic model of infant attention, look duration increases from birth to 8 or 10 weeks of age, followed by a decrease in look duration from 3 to 5 or 6 months after which look duration plateaus or may gradually increase (Colombo, 2002; Colombo et al., 1999). These phases of looking duration correspond with early developments in voluntary control, disengagement abilities, and arousal systems. Advancements in visual attention continue through early childhood as the prefrontal cortex develops. Within these developmental periods, studies show individual differences in infant attention. For example, infants with "prolonged looking" show poorer visual recognition performance than short looking infants, such that prolonged looking durations were interpreted as infants demonstrating slower processing (Colombo et al., 1991). In addition, individual differences in infants' attention to novelty shows predictive value for later cognitive functioning that outperforms standardized infant cognition measures like the Bayley MDI (e.g., Bornstein & Sigman, 1986; McCall & Carriger, 1993; Rose & Feldman, 2000). It is theorized that various mechanisms, such as individual differences in attentional disengagement, processing speed, information processing strategy and short-term memory may account for the quite impressive long-term predictability of infant visual attention for childhood intellectual functioning (Colombo, 1993; Colombo, 2002; Colombo et al., 1995; Colombo et al., 2001). Therefore, it is also of interest whether this predictive power may also be applicable to clinical populations or be beneficial for discriminating clinical from non-clinical populations.

1.2 VISUAL ATTENTION IN THE EARLY DEVELOPMENT OF CLINICAL (NON-ASD) POPULATIONS

Preterm infants. There is substantial empirical support for preterm, low birth weight infants to be considered at heightened risk for poorer cognitive outcomes (Aylward, 2002; Aylward, Pfeiffer, Wright, Verhulst, 1989; for meta-analysis, see Escobar, Littenberg, Petitti, 1991; Hack, Breslau, Aram, Weissman, Klein, & Borowski-Clark, 1992; Hoy, Bill, & Sykes, 1988; Lawson & Ruff, 2004a; Lawson & Ruff, 2004b; Rose, 1980; Rose & Feldman; 2000; Perlman, 2003). Notably, empirical evidence supports visual attention differences in this at-risk group, preterm infants, compared to full-term infants (Rose, 1980; Rose, 1983; Rose & Feldman, 2000; Rose, Gottfried, & Bridger, 1978; Rose, Gottfried, & Bridger, 1979; Ruff, 1986; Ruff, McCarton, Kurtzberg, & Vaughan, 1986). Full-term 6-month-olds demonstrated greater attention to novel test items (compared to familiar test items) on two of the three visual attention tasks, whereas six-month-olds failed to differentially attend to novel versus familiar test items (Rose, 1980). When infants viewed shapes with varied familiarization times ranging from 10 to 30 seconds, preterm infants required substantially longer familiarization time at both 6 and 12 months of age relative to full-term infants (Rose, 1983). Specifically, 12-month preterm infants tended to require at least 20 seconds of processing to display novelty effects (Rose et al., 1978; Rose et al., 1979). In addition, preterm infants demonstrate less focused attention (or periods of active examination of an object) when exploring novel objects (Ruff et al., 1986) and are slower to initiate exploration of these objects compared to full-term infants (Ruff, 1986). Collectively, these results support early visual attention differences in preterm infants across the first year of life that may be indicative of slower information processing.

Importantly, studies also show significant associations between visual attention measures and later intellectual functioning in preterm infants (as well as full-term infants; Lawson & Ruff, 2004a, 2004b; McCall & Carriger, 1993; Rose, Feldman, Wallace, & McCarton, 1989). Specifically, focused attention of 7-month-old infants predicted all follow-up cognitive assessment scores at 2, 3 and 4-5 years, while 7-month Bayley MDI failed to show any predictive value (Lawson & Ruff, 2004a). Similarly, in a low SES sample, attention to novelty across 9 visual problems at 7 months of age significantly predicted MDI/IQ at 1, 1.5, 2, 3, 4 and 5-year follow-up assessments (Rose et al., 1989). Their measure of sustained attention also showed significant associations to later IQ scores, with difficulties sustaining attention related to lower IQ, whereas 7-month Bayley MDI again yielded inconsistent correlations to later IQ (Rose et al., 1989). These results highlight how infant visual attention seems to more effectively predict cognitive functioning than standardized infant cognitive measures.

Findings indicate that focused attention even past the first year of life (1 and 2 years of age) is correlated with later cognitive performance at 3.5 years (Lawson & Ruff, 2004b). Notably, the predictive utility of focused attention among premature, low-birth weight infants has been extended to cognitive functioning at 5 years of age, with moderate correlations ranging from .27 to .44 (Lawson & Ruff, 2004a). Due to multiple risk factors in this sample, associations between focused attention and later cognitive functioning were moderated by a composite risk index comprised of gender (with male status linked to heightened risk), estimated gestational age at birth and maternal education level. This moderation model supports stronger predictive power between visual attention and later cognitive functioning among infants at higher risk (Lawson & Ruff, 2004a).

Failure-to-thrive infants. The predictive power of infant attention to novelty when presented with a series of face stimuli and abstract pattern stimuli has also shown to be beneficial for 3-year cognitive outcomes among failure-to-thrive infants (Singer & Fagan, 1984). They found a significant association ($r = .47$, $p < .02$) between their infant visual attention composite measure collected at 8 months of age and later cognitive performance on the Stanford-Binet Intelligence Scale measured at 3 years of age. Interestingly, Bayley MDI and infant visual attention were uncorrelated (Singer & Fagan, 1984), which suggests that measuring visual attention indices in infancy may provide a useful adjunct to developmental assessments of children at heightened risk for cognitive delays, including but not limited to those with failure-to-thrive histories (for review, see Corbett & Drewett, 2004; Drotar & Sturm, 1988; Elmer, Gregg, & Ellison, 1969).

Cocaine-exposed infants. When assessed with four visual recognition tasks presented in a paired-comparison paradigm, infants' visual attention to shapes, schematic face, hourglass and bull's eye forms differed based on cocaine exposure. Cocaine-exposed neonates showed less attention to the novel images than non-cocaine exposed neonates (Singer et al., 1999). Similar results have also been used to suggest that prenatal cocaine exposure is associated with lower scores on the FTII (meaning less attention to novelty) and higher rates of attentional scores in the developmentally at-risk range on this measure (which was defined as scores ≤ 53%). No significant gender differences emerged in these studies (Singer et al., 1999; Singer et al., 2005), but research supports a dose-response relationship such that increased prenatal cocaine exposure is related to poorer visual recognition performance (i.e., less attention to novelty). This dose-response relationship has been found in neonates, 6.5 months olds and 12 month-old infants with prenatal cocaine exposure (Jacobson, Jacobson, Sokol, Martier, & Chiodo, 1996; Singer et al., 1999; Struthers & Hansen, 1992). Collectively, these results support a relationship among prenatal cocaine exposure, attentional deficits and cognitive functioning.

Infants at risk for later intellectual disability. Given these promising relations between infant visual attention and later cognitive functioning, it is not surprising that a visual attention screening device (FTII) was developed for the early identification of cognitive delays among infants characterized as at-risk for intellectual disability based on infant and/or maternal medical history (Fagan, Singer, Montie, & Shepher, 1986). As previously described, the FTII is administered between the ages of three and seven months of age and is comprised of 10 different "novelty problems" that vary with infant age. Infants' attentional scores to novelty over familiar images correctly identified 75% of later intellectually delayed children and 91% of children without delays. The authors argue that these identification rates support the use of infant visual attention as a sensitive, specific and valid screening device for later intellectual disability. Furthermore, infant attention was effective in its identification of mildly delayed (IQ scores between 60 and 70) and severely delayed children (IQ scores ≤ 50; Fagan et al., 1986). This finding suggests that the effectiveness of the FTII is not simply due to a strong predictive power for severely delayed children.

In contrast, Bayley MDI scores correctly identified only 45% of the delayed children and only 38% of the typically developing children, suggesting both low sensitivity and specificity of this early standardized infant measure for later cognitive functioning (Fagan et al., 1986). This finding is consistent with the low correlations averaging around 0.18 between Bayley scores from 3-7 months of age and later standardized IQ scores collected at 3 years or older in high risk and/or clinic samples (for review, see Fagan & Singer, 1983). Collectively, these findings lend further support for the broad applicability and predictive utility of infant visual attention composites for later cognitive functioning relative to standardized infant development indices.

Infants with Fragile X syndrome. Lastly, Fragile X syndrome (FXS) is a single gene disorder with phenotypic features associated with ASD (Hall, Lightbody, & Reiss, 2008; Harris et al., 2008). Given its phenotypic similarity to ASD, the investigation of visual attention in infants with FXS (Roberts, Hatton, Long, Anello, & Colombo, 2012) may yield novel implications for infant-sibling studies. One such study examined early visual attention in infants with FXS at 9, 12 and 18 months of age during the administration of standardized games (LabTAB; Goldsmith & Rothbart, 1996) as measured by the proportion of time infants attended to the toy during unstructured play time and the latency to first disengage from the toy. Heart activity was also assessed as a psychophysiological measure of attention, with heart rate deceleration associated with focused or sustained attention.

Compared to typically developing peers, 12-month-old infants with FXS displayed prolonged look durations, less variability in heart rate and shallower heart rate deceleration

(Roberts et al., 2012). These findings support visual attention differences both in gaze and heart activity in FXS within the first year of life and suggest that infants with FXS may process information less efficiently. Importantly, severity of ASD symptomatology was also significantly associated with infant look duration (meaning, prolonged looking) and a longer latency to disengage attention (Roberts et al., 2012). These findings lend support not only for group differences in important infant looking behaviors among those with FXS but also for significant relationships between individual differences in these looking behaviors and ASD symptomatology. Notably, the direction of these results is consistent with the following extant literatures: individual differences in looking behavior (e.g., "prolonged" lookers versus short lookers) in typical development, attentional disengagement difficulties and attention to nonsocial stimuli in ASD and infant-siblings, and associations between infant visual attention and ASD symptomatology (to be described in the next section).

Summary. Across variable at-risk and clinical populations, infant visual attention measures of look duration, attention maintenance, focused attention, and attention to novelty show predictive value for identifying these clinical groups and predicting long-term intellectual functioning years later. Furthermore, this high predictive power of visual attention indices composited from multiple tasks or "problems" occurs in the context of uncorrelated standardized measures of infant cognitive performance. Therefore, these findings highlight the potential utility of applying eye-tracking tests in clinical settings for enhanced early identification of at-risk or clinical populations. In addition, the predictive value of visual attention composites across diverse infant risk groups and those later given a clinical diagnosis suggests that further investigation of infant risk groups, such as those at heightened genetic risk for ASD, is warranted.

1.3 VISUAL ATTENTION IN THE DEVELOPMENT OF ASD

Attentional disengagement differences in early ASD. Unlike typical infants who develop greater control over their abilities to disengage and re-engage attention over the early months of infancy, research suggests that “sticky attention” (i.e., difficulties disengaging and re-engaging attention) may persist beyond infancy in children with ASD. Children with ASD aged 3-7 years old continue to display “sticky attention” tendencies with lower rates of disengagement from stimuli. This significant attentional deficit in autism has been demonstrated with a basic visual orienting task (Landry & Bryson, 2004). After engaging on a central fixation stimulus, an additional stimulus was presented on either side such that there were two competing stimuli on the screen. Children with ASD displayed a significantly longer latency to disengage with the central stimulus compared to typically developing children and children with Down syndrome, suggesting that a difficulty with attentional disengagement may be specific to autism (Landry & Bryson, 2004). The extent of this impairment in attentional disengagement is also illustrated by the result that the children with ASD failed to disengage from the initial stimulus on 20% of the experimental trials (Landry & Bryson, 2004). This disengagement impairment appears consistent across IQ, such that children with ASD of average or above average IQs tend to display “sticky attention” as do children with lower IQs (Landry & Bryson, 2004). Furthermore, difficulties disengaging attention from a central stimulus have also been found in 14-month-old infants later diagnosed with ASD (Elsabbagh et al., 2013).

Visual disengagement impairments present in Landry and Bryson’s (2004) and Elsabbagh and colleagues’ (2013) tasks also generalize to more naturalistic interactions. Specifically, infants with an ASD sibling displayed fewer gaze shifts to and from their parents’ faces than infants without an ASD sibling, meaning that disengagement deficits are apparent in the parent-child interactions of infants at high genetic risk for ASD (Ibanez, Messinger, Newell, Lambert, & Sheskin, 2008). Due to this early difficulty with disengagement, HR infants may process a different set of information than typical infants who are more skilled at disengaging attention and incorporating more information from multiple sources, such as social information obtained from parents' facial expressions. More broadly, infants with "sticky attention" may process information and respond differently behaviorally, such that they show different ways of exploring their environments.

However, it should be noted that Chawarska and colleagues (2010) found that toddlers with ASD did not differ from typically developing (TD) toddlers when disengaging from non-social stimuli based on saccadic reaction times. However, they did exhibit faster saccadic reaction times when disengaging from a face than TD toddlers or those with developmental delays (DD). This finding suggests that the group differences in attentional preferences for social versus non-social stimuli may have yielded a comparatively faster disengagement from faces in toddlers with ASD, since faces are less salient to toddlers with ASD. Due to the high saliency of faces to the visual attention of TD and DD toddlers, there is a higher cost of disengagement from faces among TD and DD than ASD groups.

Attentional differences to social vs. nonsocial stimuli in early ASD. Extensive research has examined differences in visual attention to social versus non-social stimuli in ASD. Most notably, when viewing videotape clips of complex social situations that present faces and objects simultaneously, adolescents with ASD attended to objects twice as much as age and verbal IQ-matched controls, whereas typical individuals attended to the eye region of faces twice as much as individuals with ASD (Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Research indicates that children with ASD orient less to faces than do typical children (Bernabei et al., 1998; Maestro et al., 1999; Osterling & Dawson, 1994; for face processing review, see Webb, Neuhaus, & Faja, 2016; Zwaigenbaum et al., 2005) and spend comparatively more time looking at objects than typically developing and developmentally delayed toddlers (Swettenham et al., 1998). This attentional preference for objects rather than social stimuli is also supported by young ASD children's performance on a visual exploration task in which they perseverated more on object stimuli than social stimuli (Sasson et al., 2011). Given ASD is associated with spatial working memory deficits to complex stimuli like faces and social scenes (Minshew & Goldstein, 2001; Williams, Goldstein, & Minshew, 2005), these findings suggest that attentional differences may partially reflect and/or contribute to spatial working memory deficits. A similar attentional bias to nonsocial stimuli has been demonstrated during dynamic, more ecologically valid visual attention tasks as well. When presented with a simple preferential looking paradigm of dynamic social images and dynamic geometric images, toddlers with ASD spent a greater proportion of time attending to the geometric images than to the social images compared to typical and developmentally delayed children (Pierce, Conant, Stoner, & Desmond, 2011). In other words, this lack of visual attention to people positively predicts ASD diagnosis and supports an association between visual attention tendencies and ASD early in development.

Although infant-sibling findings are somewhat mixed, differences in visual attention to social versus nonsocial stimuli have been associated with ASD even in infancy. For example, infants at high-risk for ASD exhibit slower looking responses to faces and faster looking responses to objects than do low-risk infants (McCleery, Akshoomoff, Dobkins, & Carver, 2009). In addition, 6-month-old infants later diagnosed with ASD demonstrated reduced attention to inner facial features when presented with speaking faces (Shic, Macari, &

Chawarska, 2014) and reduced attention to a person shown in a naturalistic scene (Chawarska, Macari, & Shic, 2013). However, a few studies failed to find atypical visual attention to static faces (Elsabbagh et al, 2013) and facial movements (Elsabbagh et al., 2014) at 7 and 14 months of age. It may be that stimulus characteristics, such as salient motion cues, may reduce attentional differences demonstrated by infants later diagnosed with ASD. It is also possible that visual attention patterns in ASD may change across early development, such that attentional differences may or may not occur at a particular time point based on developmental age or in interaction with stimulus characteristics. Three such studies provide empirical support for the importance of examining how visual attention may change across early development. The first two studies found a gradual reduction in visual attention to the eye region during a dynamic video (Jones & Klin, 2013) and to faces during live observation (Ozonoff et al., 2010) across the first few years of life. Most recently, Jones and colleagues (2016) found that 6-month-old infants with a later ASD diagnosis displayed overall shorter looking durations and later peak looks to faces (but not objects) during repeated presentation of visual stimuli than non-ASD infants; however, no significant effects were found at 12 months. These findings suggest that early attentional markers of ASD are dynamic across infancy and highlight the importance of investigating longitudinal changes in visual attention in ASD. It also follows that another important consideration is the attentional process(es) being assessed as infants later diagnosed with ASD may not display aberrant looking behaviors in all aspects of attention. For example, are the variables of interest capturing visual attention in terms of an initial orienting response, the maintenance of attention and/or the location of infant looking? As posited by Jones and colleagues (2016), visual orienting responses may be intact in early ASD, whereas infants' abilities to maintain attention may differ in ASD.

In summary, these findings suggest that individuals with ASD display different visual attention patterns to social stimuli. These attentional differences seem to emerge early in the development of ASD, as recent findings suggest that infants later diagnosed with ASD and toddlers with ASD tend to display reduced attention to social stimuli (e.g., Chawarska et al., 2013; Jones & Klin, 2013; Jones et al., 2016; McCleery et al., 2009; Ozonoff et al., 2013; Shic et al., 2014).

Relations between visual attention and various functioning levels. In addition to group differences in visual attention, there is significant empirical support that differences in visual attention among those with ASD are associated with individuals' functioning. For example, analyses from Klin and colleagues' (2002) study described above indicated that longer visual fixations to the mouth region of the face were related to higher levels of social competence and lower levels of ASD social impairment. In contrast, longer visual fixations to objects were associated with higher levels of ASD social impairment and lower levels of social competence (Klin et al., 2002). Similar results have also been found in children with ASD. Slowed face learning abilities have been shown to be related to higher ASD severity scores, lower verbal scores and slowed object learning (Webb et al., 2010), whereas longer duration of visual object exploration at 12 months of age was associated with higher ASD severity scores and lower cognitive and language outcomes (Ozonoff et al., 2008). Broadly, these findings suggest that the salience of social and non-social stimuli for visual attention is related to how individuals engage and function in the environment.

Infant research also supports relationships between visual attention tendencies and functioning in HR infants. For example, evidence suggests that 12 month-old infants' difficulty disengaging visual attention in Landry and Bryson's (2004) task predicts ASD symptoms and the number of social-communicative impairments present at two years of age derived from the Autism Diagnostic Observation Schedule (ADOS-G; Lord, Rutter, DiLavore, & Risi, 1999), a gold standard diagnostic tool for ASD that assesses ASD symptoms from semi-structured observations. Similarly, more recent evidence supports a strong association between infants' delayed sensitization to face stimuli and higher childhood ADOS scores (Jones et al., 2016). Thus, research supports the predictive value of investigating attentional processes for later functioning.

The utility of attention composites. Stimuli applied to the study of early ASD are widely variable, ranging in both subject (e.g., faces, social scenes, objects, geometric patterns) and stimulus type (e.g., static, dynamic, visual-only, audiovisual). Nonetheless, across divergent stimuli and visual attention methodologies, the extant literature largely supports that there are visual attention differences in individuals with ASD. Current conceptualizations assert ASD as a neurodevelopmental disorder involving early aberrant brain and behavioral development (Hellendoorn, Wijnroks, & Leseman, 2015; Minshew & Williams, 2007; Mottron, Dawson, Soulières, Hubert, & Burack, 2006; Mundy & Neal, 2000; Williams, Goldstein, & Minshew, 2006), including core attentional processes. For example, there is empirical evidence indicating individuals with ASD can demonstrate superior local processing abilities. It is posited that local processing may serve as a default processing mode in ASD, thereby avoiding the attentional biases towards global processing demonstrated in typical development (Mottron & Burack, 2001; Mottron, Dawson, Soulières, Hubert, & Burack, 2006).

Given that a local processing strategy is associated with more prolonged looking and less efficient processing (Colombo et al., 2001), a core bias for local processing in ASD would result in broad differences in the attentional profiles of those with ASD as measured by looking behavior across stimuli subject and type. Therefore, it is not surprising that visual attention differences in ASD populations have emerged across a diverse array of eye-tracking tasks. Yet, only one study has evaluated the utility of creating aggregate eye tracking metrics from these diverse tasks for accurately discriminating children with ASD (ages 3-9 years) from a clinic-referred, non-ASD comparison group (Frazier et al., 2016). The inclusion of diverse eye-tracking tasks may be beneficial for reducing the effects of any singular stimulus task and allows for simultaneous quantification of general looking patterns to social and nonsocial stimuli. Quantification of looking behavior to social and nonsocial stimuli was conducted by defining regions of interest (ROIs), which are identified *a priori* by the research team as social or nonsocial areas of the scene. Their eye-tracking composite, named the Autism Risk Index (ARI), reflected average attentional dwell times to social and nonsocial ROIs from 6 diverse eye-tracking tasks including static facial emotions, biological motion and dynamic scenes (for example stimuli, see Figure 1). Frazier and colleagues (2016) found variable but modest discriminative ability for ASD utilizing individual ROIs, but results indicated composite ARI scores demonstrated high diagnostic accuracy (area under the curve > .90) as well as significant positive correlations with ADOS-2 severity scores but not language ability. Moreover, these visual attention composites outperformed the Social Responsiveness Scale (SRS-2; Constantino & Gruber, 2007), a standardized parent report measure of ASD-related symptoms. These findings suggest that visual attention composites may have heightened predictive power over an individual eye-tracking task or single ROI. Furthermore, the predictive utility of visual attention composites can also be applied to symptom severity and is not simply captured by language ability.

Summary. The extant literature supports visual attention differences in ASD across the lifespan but as early as infancy. These attentional differences include basic attentional abilities, such as attentional disengagement as well as the distribution of attention to social and nonsocial stimuli. Furthermore, these visual attention differences are predictive of various indices of later functioning. The predictive power of visual attention for ASD has recently been applied to objective diagnostic purposes and shown high diagnostic accuracy when using composite scores aggregated from varied stimulus types and items (Frazier et al., 2016). The diagnostic accuracy of the ARI visual attention composite actually outperformed a standardized report measure used in clinical settings, the SRS-2. Thus, these findings collectively support the predictive value of creating visual attention composites for ASD and individuals' functioning. Although Frazier and colleagues (2016) applied the concept of visual attention composites in a novel manner, this technique of calculating visual attention composites has yet to be applied to infant-sibling research until the present study.

1.4 THE PRESENT STUDY

Given the extant literature supporting both visual attention differences across the lifespan in ASD as well as the predictive value of visual attention composites for later intellectual functioning in typical and clinical populations, the present study focused on visual attention composites using infants with and without heightened genetic risk for ASD. The present study recruited infant-siblings (infants with and without an older sibling with ASD). Eye-tracking data were collected while infants viewed various stimuli, including static faces, dot patterns, objects and dynamic videos. Visual attention composite scores from these eye-tracking tasks were calculated to obtain general attentional profiles of infants at high (HR) and low genetic risk (LR) for ASD.

The first aim was to investigate group differences in infants' visual attention across 11 and 16 months of age based on infant genetic risk status (HR vs. LR). It was predicted that HR and LR infants would show differences in visual attention composited across tasks at 11 and/or 16 months of age. Secondly, this study aimed to explore infant attentional composites (at 11 and 16 months) as predictors of later childhood outcome classifications at 24, 36 and/or 48 months of age. Outcome classifications consisted of: ASD, typically-developing (TD) and non-typically developing (NT). The NT group referred to children without ASD who showed global developmental delay, language delays and/or social functioning concerns. It was predicted that ASD, NT and TD infants would differ in visual attention at 11 and/or 16 months of age, such that attentional composites would be predictive of ASD diagnosis, and more broadly, atypical development (i.e., ASD and NT). Aim 3 was to examine relationships between visual attention composites and later childhood cognitive/developmental functioning across infancy. Lastly, the fourth aim was to assess the predictive value of visual attention composites for later functioning relative to collected standardized infant measures. Consistent with the extant literature showing relationships between infant looking behavior and later childhood IQ in both typical and clinical populations (e.g., Fagan, 1990; Fagan et al., 1986; Lawson & Ruff, 2004; for meta-analysis, see McCall & Carriger, 1993; Roberts et al., 2012; Rose et al., 1989; for review, see Rose et al., 2004; Rose et al., 2012; Singer et al., 1999), it was expected that relationships would also emerge in this infant-sibling study.

2.0 METHODS

2.1 PARTICIPANTS

Participants consisted of 47 infant siblings of children with ASD (high-risk infants; HR) and 39 infant siblings of typically developing children (low-risk infants; LR). HR infants had at least one older sibling diagnosed with ASD, whereas LR infants had an older sibling(s) that did not have ASD nor other first or second-degree relatives diagnosed with ASD. In this longitudinal study, infants participated in attentional tasks at both 11 and 16 months of age as well as follow-up assessments at 24, 36 and/or 48 months of age. Participant demographics can be found in Table 1.

Infants were recruited through advertisements and flyers. The ASD diagnosis of HR infants' older sibling was confirmed utilizing the Autism Diagnostic Observation Schedule-Generic (ADOS-G; Lord, Rutter, DiLavore, & Risi, 1999) and the Autism Diagnostic Interview-Revised (ADI-R; Lord, Rutter, & LeCouteur, 1994). A phone screen was used with LR infants' parents to ensure that older siblings did not have ASD diagnoses and that no first or second-degree relatives had been diagnosed with ASD. In addition, any infant who had problems during labor and delivery, a birth weight less than 2500 grams or any form of brain injury or birth defect was excluded from the study.

At each infant time point (11 and 16 months of age) and each follow-up assessment time point (24, 36 and/or 48 months of age), HR and LR infants were assessed with the Mullen Scales of Early Learning (MSEL; Mullen, 1995). The Mullen is a well-established measure of language and cognitive development with four subscales: visual reception, fine motor, receptive language and expressive language. A developmental quotient (DQ) was calculated by combining the receptive language, expressive language, visual reception and fine motor age equivalents.

In addition, for participants who had reached 24, 36 and/or 48 months of age, infants were assessed for ASD on the ADOS-G (Lord et al., 1999) and ADI-R (Lord et al., 1994). Lastly, participants' language development was assessed at 24-month follow-up assessments using the MacArthur-Bates Communicative Development Inventory (CDI; Fenson et al., 1996), a widely-used parent report measure of early language competence. Based on these assessment tools and clinical judgment (by highly-experienced Clinical Psychologists), infants were assigned to one of three outcome groups: ASD, non-typically developing (NT) or typically-developing (TD). Infants diagnosed with ASD met at least spectrum cut-offs on the three ADOS-G total scores (Communication Total, Social Interaction Total and Combined Communication and Social Interaction Total) and the diagnosis was confirmed by the clinical psychologist's review. The NT group consisted of infants who displayed delayed global development, atypical language skills and/or social concerns. Delayed global development was characterized by Mullen Visual Reception and Receptive Language scores at least 1.5 standard deviations below the normative mean and/or clinical opinion. An NT designation due to non-typical language skills was defined by Mullen (1995) scores at least 1.5 standard deviations below the normative mean for only Expressive and/or Receptive Language. Alternatively, infants may have had MacArthur-Bates CDI Words Produced below the 10^{th} percentile and/or received the classification due to clinical opinion. Lastly, infants were classified as showing social concerns if they demonstrated at least spectrum cutoffs on the ADOS-G Social Interaction total only or score within 2 points of spectrum cutoffs on the combined Communication and Social Interaction Total and/or clinical opinion. Infants who did not meet any of the criteria described above were designated as TD. Classification criteria are described in Table 2.

If multiple follow-up assessments were conducted (e.g., at 24, 36 and 48 months of age), outcome classification from the oldest age point was used (e.g., 48 months of age). The sample consisted of 68 TD infants, 7 NT infants and 10 infants with ASD. Further diagnostic classification information and participant characteristics based on outcome group are summarized in Table 3.

2.2 PROCEDURE

Infants' visual attention was recorded using eye-tracking technology. Infants participated in the eye-tracking procedures at 11 and 16 months of age. Standardized developmental assessments were provided at 11, 16, 24, 36, and/or 48 months of age. Lastly, infants participated in follow-up diagnostic outcome classification assessments at 24, 36 and/or 48 months of age.

Apparatus. Infant participants were seated in a high chair located in a dark, quiet room 162 cm from a large rear projection movie screen measuring 69 x 91 cm (visual angle of 24 x 31 degrees). A Tobii X120 stand-alone eye-tracker was placed on a table between the infants and the projection screen. This position was 81 cm from the screen. A Dell Dimension 9200 and

Tobii Studio software (Version 2.0.6) was used to rear project stimuli onto the projection screen and record eye movement data. At a sampling rate of 60 Hz, the eye-tracker records eye movements with a 0.2 degree spatial resolution, 0.5 visual angle degree accuracy and 0.3 degree drift.

Stimuli. Infant participants viewed the following series of stimuli consisting of six static stimuli sets and six dynamic videos. Stimuli order was randomized across participants.

Emotion face stimuli. Infants participated in a visual paired comparison task involving the presentation of a female face expressing a static smile paired next to a photograph of the same person displaying a neutral expression. Stimuli were developed on the empirically-supported premise that infants would look longer at the smiling versus neutral face (Farroni, Menon, Rigato, & Johnson, 2007). Three levels of face pairs varied in smile intensity (with four trials per level for a total of 12 trials). Low intensity was depicted with neutral/closed-mouth smiling, whereas neutral/open-mouth smiling and neutral/exaggerated smiling designated moderate intensity and high intensity, respectively. The four trials per level included two different female identities per level (for example, see Figure 4). Each identity pairing was subsequently followed by a left/right reversal of the face pair. Each trial was presented for 8 seconds. A single animation was displayed between trials as an attention grabber for infants to reorient to the screen.

Attractiveness face stimuli. Infant participants were presented with a series of female faces during a visual paired comparison task. Stimuli consisted of 12 colored photographs (with visual angle of approximately 10 x 14 degrees) depicting naturalistic female faces that were presented in pairs (for a total of six female face pairs). Levels of emotional expression were equivalent but attractiveness (as previously rated by adults) varied across stimuli (for example, see Figure 5). Each face pair was presented for 8 seconds. Between face pair trials, a cartoon animation was displayed to reorient infant participants' attention to the screen prior to the next trial.

Face prototype stimuli. Infants viewed 12 colored photographs of human faces that were approximately 12 x 19 degrees of visual angle. Each face was presented individually for 5 seconds and depicted the *same* male identity with manipulated internal facial features and spatial distances from the prototype. The prototype refers to the original facial image that portrays the statistical average in spatial distances and facial features. The following facial aspects were manipulated using a facial morphing program: nose/mouth distance, nose width, lip thickness and forehead height (Gastgeb, Wilkinson, Minshew, & Strauss, 2011). A cartoon animation was shown at the center of the screen to reorient infant participants' attention prior to the next trial.

Dot prototype stimuli. Infant participants were presented with a total of six-dot pattern pairs separated by a central vertical black line on the screen (for example, see Figure 7). Stimuli were created using procedures of Gastgeb, Dundas, Minshew and Strauss (2012) and presented for 10 seconds each. The dot prototype was created by placing nine black dots into a central 30 x 30 cell area using Excel (with similar results to the prototype creation conducted by Kéri, Kálmán, Kelemen, Benedek and Janka in 2001) and subtended an area of 26 x 32 degrees of visual angle. Each dot pattern stimulus was generated by moving individual dots a predetermined distance from the dots of the original prototype (see Gastgeb et al., 2012, for additional stimulus design). Between trials, infants viewed a cartoon animation to re-engage attention to the center of the screen.

Face memory stimuli. Stimuli consisted of 15 face pairs of black and white photographs of naturalistic female faces portraying neutral expressions. Each face was cropped into an oval shape to occlude hair cues (for example, see Figure 8) and was approximately 10 x 14 degrees of visual angle. A subset of three face pairs were presented in the following order with each subset using one of five different face identities of interest: same identity face pair, same/different identity face pair and its left/right reversal. Therefore, this pattern was repeated five times using different face stimuli with each face pair. The first five trials (called habituation/familiarization trials) were presented for 15 seconds each, followed by the 10 remaining face pairs (called test trials) presented for 8 seconds each. A cartoon animation was shown between face pair presentations to reorient infant participants' attention to the screen.

Object memory stimuli. Using the same paired comparison design as the face memory task described above, stimuli consisted of 15 object pairs using photographs of chairs (e.g., armchair, office chair, lawn chair, high chair; for example, see Figure 9). All stimuli were black, white and/or gray in color and presented for 15 seconds. Five subsets of three object pairs each were presented in the following order: same object pair (two identical chairs presented simultaneously), same/different object pair and its left/right reversal. Therefore, repetition of this pattern five times using different object stimuli for each subset yielded a total of 15 object pairs. The first five trials (or habituation trials) were presented for 15 seconds each, followed by presentation of the remaining 10 object pairs (or test trials) for 8 seconds each. A cartoon animation was displayed between trials to reorient participants' attention to the center of the screen.

Dynamic video stimuli. Stimuli consisted of six dynamic video clips from the television show, *Mister Rogers' Neighborhood*, ranging from approximately 30 to 45 seconds. Each video depicted naturalistic interactions and provided both visual and auditory information (for example, see Figure 10). Each entire scene was approximately 26 x 17 of visual angle. In video

1, a woman converses with a puppet while standing in front of a static background. In video 2, Mr. Rogers looks directly at the camera and sings a song in front of a static background. In video 3, Mr. Rogers shows and talks about a wooden toy airplane, several wooden blocks and a rubber band. During the scene, he makes eye contact with both the airplane when he describes it and looks directly at the camera when addressing the audience. Mr. Rogers is seated in a chair in front of a static background. In video 4, Mr. Rogers shows and talks about a snorkel mask while seated in front of a static background. He makes eye contact with the object while describing it but also makes eye contact when addressing the audience. In video 5, Mr. Rogers converses with a woman while seated on the edge of a boat, such that the movement of water leads the figures' bodies to move upward and downward relative to the background. Mr. Rogers and the woman hold eye contact with one another during their conversation. In video 6, Mr. Rogers has a conversation with an elderly woman while both are seated in front of a static background. Both individuals make eye contact with one another during their conversation. The order of stimuli presentation was randomized across individuals.

Eye-tracking and Calibration Procedures. Infants first sat in a high chair accompanied by a caregiver and viewed a cartoon to attract their attention to the projection screen. After infants oriented to the screen, the cartoon was replaced by a picture of a red rattle that made noises and oscillated, hence, attracting infants' attention for eye-tracking calibration. This image served as the calibration stimulus. The experimenter used the live view of infants' eye movements during the calibration to assess when infants had oriented to the rattle. Once infants had oriented to the stimulus, the experimenter pressed a button to shift the rattle to a different location on the screen. Successful calibration was achieved by repeating this sequence until infants accurately oriented to the stimulus for a total of five different positions.

After the calibration task, infants viewed up to six static stimuli sets and six dynamic videos. Eye-tracking data was recorded during each task. Infant participation was terminated prior to completion of all 12 stimuli sets if infants displayed marked upset or fussiness during testing.

2.3 DATA REDUCTION AND ANALYSIS

Designating Regions of Interest (ROIs). The duration of time infants spent looking to different aspects of the stimuli was determined by creating regions of interest (ROIs) with Tobii Studio software (for example, see Figure 11). The drawn ROIs included the total viewing area and relevant aspects of the stimulus or scene (i.e., people, faces, objects). To adjust for motion during the dynamic video clips, ROIs were shifted in position and size across each frame as needed.

Calculating Visual Attention Composites.

General Attention Composites. To obtain measures of how infants generally attended to various stimuli in their environment, several visual attention scores were composited from all eye-tracking tasks. Overall attention composite measures are named and summarized below. (See Table 4 for operational definitions used for calculating each composite score.)

(a) Proportion of looking (i.e., total amount of looking across tasks divided by total possible looking time)

(b) Active scanning (or "sticky attention" proxy; i.e., total number of fixations divided by total looking time)

(c) Attention to figure vs. background (i.e., ratio of total looking time to figures or relevant aspects of the scene like people and objects to total looking time to the background)

Attention Composites Utilizing Relevant Task Subsets. To assess how infants attended to different aspects of visual stimuli in the environment, several additional visual attention scores were calculated. These visual attention measures reflected composites derived from multiple eye-tracking tasks but only those tasks relevant to the specific attentional characteristic under investigation. These attention composite measures targeting stimulus properties are named and described below (for more detailed information, see Table 4):

(a) Attention to novelty (i.e., looking time to novel images during test trials of the object memory task and face memory task divided by total looking time on tasks)

(b) Attention to static vs. dynamic stimuli (i.e., ratio of looking time during presentation of the six static stimuli sets divided by total possible looking duration to total looking time to the six dynamic videos divided by total possible looking duration)

(d) Attention to social vs. nonsocial stimuli (i.e., total looking time to faces presented during the face prototype and face memory tasks divided by total looking time to objects presented during the dot prototype and object memory tasks. Alternatively, for infants who did not complete all four tasks, two-task ratios were calculated as follows: (i) total looking time to faces presented during the face prototype task divided by total looking time to objects presented during the dot prototype task or (ii) total looking time to faces presented during the face memory task divided by total looking time to objects presented during the object memory task.)

(e) Maintenance of attention (i.e., looking time during first half of presentation of each dynamic video divided by looking time during second half of presented video averaged across all presented video tasks)

Analytic Plan. The analytic plan was comprised of two sets of analyses. The first set of analyses focused on statistical exploration and validation for the *a priori* operational definitions used in creating the visual attention composites. Principal-components analysis using the individual eye-tracking tasks and tests of intercorrelations among visual attention composites were conducted for this purpose. After establishing the visual attention composite scores, the second set of analyses were developed to address the four main aims of the present study. Broadly, these analyses explored visual attention composites across infancy (11 and 16 months of age), genetic risk status (HR and LR) and later childhood outcome classification (ASD, NT and TD).

To examine group differences in visual attention composites between HR and LR infants across infancy, two-way repeated measures analyses of variance (ANOVA) were conducted. Genetic risk status (HR vs. LR) served as the between-subjects factor and age (11 vs. 16 months) served as the within-subjects factor. The second aim of the study was to explore attentional composites as predictors of later childhood outcome classifications (e.g., ASD, NT and TD) at 24, 36 and/or 48 months. Binary logistic regression was conducted using risk and infant visual attention composites at 11 or 16 months to predict atypical development (i.e., ASD or NT). Similarly, binary logistic regression using risk and infant visual attention composites was conducted to predict specifically a later ASD diagnosis as well. Logistic regressions were conducted separately for 11-month and 16-month composites. In addition, descriptive statistics were provided for infants' visual attention composites at 11 and 16 months based on outcome group. Analyses to assess for group differences based on outcome classification were not feasible given the small sample sizes of the ASD and NT groups (10 and 7, respectively).

The third aim was to examine relationships between visual attention composites and later childhood cognitive/developmental functioning across infancy. Multiple linear regression was conducted using independent variables, which included visual attention composites and genetic risk status, to predict 36-month Mullen developmental quotients (DQ). Separate analyses were conducted at 11 and 16 months. Lastly, the fourth aim of this research was to assess the predictive value of visual attention composites for later intellectual functioning relative to collected standardized infant measurement. Similar multiple linear regression was conducted with the addition of infant Mullen DQs (at 11 and/or 16 months) as an independent variable with significant predictors from Aim 3 analyses for predicting childhood Mullen DQs at 36 months of age. Again, separate analyses were conducted at each infant age point.

3.0 RESULTS

3.1 DATA SCREENING OF *A PRIORI* ATTENTIONAL COMPOSITES

The distributions of each visual attention composite for HR and LR infants were assessed for extreme outliers with the two age points (11 and 16 months) conducted separately. Extreme outliers were identified as values lying more than three times the interquartile range either below quartile 1 (Q1) or above quartile 3 (Q3) of the distribution and were removed from statistical analyses. Across all seven composites, a total of 11 extreme outliers were removed from the 11-month data and 12 extreme outliers were removed from the 16-month data (for frequencies by composite, see Table 5). Extreme outliers did not systematically vary by risk group with 52% of removed outliers designated as HR data points. In addition, only two of the 23 removed data points were attributed to infants later diagnosed with ASD, suggesting that extreme outliers were not simply driven by an ASD diagnosis.

3.2 PRINCIPAL-COMPONENTS ANALYSIS OF *A PRIORI* VISUAL ATTENTION COMPOSITES

The 12 individual eye-tracking tasks (measured by look duration) were subjected to a principal-components analysis with varimax rotation at 11 and 16 months. The 11-month results suggested a four-component solution after which the eigenvalue fell below 1.00. Of the four components, two components consisted of one task each, so a minimum of one and a maximum of four components were considered. Examination of a two-component solution yielded a clean and theoretically-supported solution, which became less interpretable with three- and four-component solutions. Therefore, it was concluded that adding components beyond two was not adequately beneficial to the overall solution. The two-component solution accounted for 49.29% of the variance (see Table 6). The first component was labeled as "Static" and was comprised of all eye-tracking tasks that presented static stimuli, whereas the second component was labeled as "Dynamic" for its inclusion of dynamically-presented tasks.

The principal-component analysis with the 16-month data yielded an initial three-component solution using an eigenvalue threshold of 1.00. Again, one-, two- and three-component solutions were considered. The two-component solution reflected a theoretically-grounded and interpretable solution in which the same two components ("Static" and "Dynamic") emerged as in the 11-month analysis. In comparing this result to the three-component solution, findings indicated that the addition of the third component did not substantially benefit the overall solution but provided a redundant factor that captured more nuanced variability among the dynamic stimuli. Thus, it was concluded to proceed with the two-component solution (Static and Dynamic) that accounted for 57.56% of the variance in tasks' look durations (see Table 6). By proceeding with the two-component solution, additional calculations to include only static stimuli and only dynamic stimuli were made for the subset of *a priori* visual attention composites that were calculated using all 12 stimuli. This subset was comprised of proportion of looking, active scanning and attention to figure versus background. Calculations using the two-component solution of Static and Dynamic factors yielded the following *data-driven* composites: proportion of looking during static tasks, proportion of looking during dynamic tasks, active scanning during static tasks, active scanning during dynamic tasks, attention to figures versus background during static tasks and attention to figures versus background during dynamic tasks. Each of these *data-driven* composites was calculated at 11 months and 16 months.

3.3 DATA SCREENING OF *DATA-DRIVEN* ATTENTIONAL COMPOSITES

As conducted for the data screening of *a priori* attentional composites, the distributions of each of the six *data-driven* composites (proportion of looking, active scanning and attention to figure vs. background calculated separately for static tasks and dynamic tasks) for HR and LR infants were assessed for extreme outliers with the two age points (11 and 16 months) analyzed separately. A total of 17 extreme outliers were removed from further statistical analyses (for frequencies by *data-driven* composite, see Table 7). Forty-one percent of removed outliers were LR data points, suggesting that removed data did not systematically vary by genetic risk status. Similarly, there was no evidence to support removed data points were driven by an ASD diagnosis since an ASD diagnosis was associated with only four of the extreme outliers.

3.4 INTERCORRELATIONS AMONG VISUAL ATTENTION COMPOSITES

Pearson's product-moment correlation coefficients were calculated to assess the extent of intercorrelations among the *a priori* visual attention composites and to identify any issues of multicollinearity. These preliminary correlational analyses were conducted separately at 11 months (see Table 8) and 16 months (see Table 9). Only three positive correlations at 11 months and two positive correlations at 16 months yielded a *p*-value less than 0.05. Given that 49 correlations were calculated at each age point, a Bonferroni correction yielded an adjusted alpha level of 0.001. Using the adjusted alpha, at 11 months, the static vs. dynamic attention composite and the active scanning composite were positively correlated ($r^2 = 0.18$, $p < 0.001$). However, the intercorrelation was relatively low, such that creating a combined composite was not warranted. No other *a priori* composite variables were significantly and positively correlated at 11 or 16 months, which suggests a lack of multicollinearity among the *a priori* composites.

In addition, correlational analyses of the *data-driven* attentional composites were conducted using Pearson's product-moment correlation coefficients to assess for intercorrelations among the *data-driven* attentional composites and to identify any issues of multicollinearity with the *a priori* composites. Analyses were conducted separately at 11 months (see Table 10) and 16 months (see Table 11) using a Bonferroni correction (of adjusted alpha = 0.0006) for the 78 comparisons at each age point. Since correlational analyses yielded the same pattern of findings at 11 and 16 months, results are described together. As expected, each *data-driven* composite (e.g., proportion of looking during static tasks) was significantly and positively correlated with the *a priori* composite it was derived from (e.g., proportion of looking) at both ages (see Table 10 and 11). In addition, a significant positive correlation was found between the *data-driven* active scanning during dynamic tasks composite and the static versus dynamic attention composite (both 11 and 16 months: $r = 0.59$, $p < 0.001$). However, results indicated that these two variables are only moderately correlated and do not warrant a collinearity issue for further analyses. No other significant positive correlations were found at 11 or 16 months. Thus, to address the multicollinearity issue between *a priori* composites and their *data-driven* counterparts, subsequent analyses using regression or modeling approaches do not simultaneously include both the *a priori* composite with its two-component versions (static tasks only and dynamic tasks only). That is, *a priori* and *data-driven* approaches are tested separately.

Interestingly, no significant positive correlations between the *data-driven* composite calculated using static tasks and that same composite calculated using only dynamic tasks were found at either age. Results indicate that infants' looking behavior during static and dynamic tasks were not correlated with one another as measured by proportion of looking, active scanning and attention to figure versus background. Therefore, both the static and dynamic versions of the proportion of looking, active scanning and attention to figure versus background composites were included simultaneously in relevant subsequent analyses without multicollinearity issues.

3.5 VISUAL ATTENTION ACROSS 11 AND 16 MONTHS BASED ON RISK STATUS

Separate 2 (age) by 2 (risk status) repeated measures ANOVAs were conducted to investigate the development of visual attention profiles from 11 to 16 months of age in HR and LR infants. Risk status served as the between-subjects factor and age served as the within-subjects factor. Dependent variables consisted of seven *a priori* visual attention composite scores and six *data-*

driven attentional composites. The *a priori* composites were: proportion of looking, active scanning, attention to figure versus the background, attention to novelty, attention to static versus dynamic stimuli, attention to social versus nonsocial stimuli and maintenance of attention. The *data-driven* composites consisted of each of the following calculated separately for static tasks only and dynamic tasks only: proportion of looking, active scanning and attention to figure versus background. Descriptive data of visual attention composite scores is provided in Table 12. Significant findings of these repeated measures analyses are described below (for all results, see Table 13).

Proportion of looking. The 2 (risk status) by 2 (age) repeated measures ANOVA indicated a significant main effect of age on the proportion of infants' looking ($F(1,83) = 446.06$, $p < .001$, partial η^2 of age = 0.84, observed power = 1.00, Cohen's d = 2.45). Overall, infants increased the proportion of time spent looking at stimuli from 11 months ($M = 0.35$, $SD = 0.12$) to 16 months of age ($M = 0.67$, $SD = 0.14$). There were no significant main or interaction effects with risk status, meaning that the proportion of looking composite did not vary based on infants' genetic risk status.

Proportion of looking (static tasks only). The 2x2 repeated measures ANOVA yielded a significant main effect of age on the proportion of looking during static tasks ($F(1,84) = 4.44$, $p < .05$, partial η^2 of age = 0.05, observed power = 0.55, Cohen's d = 0.29). Infants demonstrated an increase in the proportion of looking during static tasks from 11 months ($M = 0.33$, SD = 0.13) to 16 months ($M = 0.37$, $SD = 0.15$). There were no significant main effects of risk status or interaction effects, indicating that infants' looking to static tasks did not significantly differ across HR and LR groups.

Proportion of looking (dynamic tasks only). The 2x2 repeated measures ANOVA did not show any significant main or interaction effects of risk and age on the proportion of looking to the dynamic tasks.

Active scanning. The 2x2 repeated measures ANOVA yielded a trending interaction effect of risk and age on the number of fixations per second of looking time ($F(1,84) = 3.04$, $p < .09$, partial η^2 of interaction = 0.04, observed power = 0.41). No significant main effects of risk or age were found. Post-hoc analyses indicated only one statistically significant comparison, in which LR infants showed higher active scanning composite scores at 16 months ($M = 2.97$, $SD = 0.58$) than 11 months ($M = 2.79$, $SD = 0.51$); $t(38) = -2.07$, $p < 0.05$). All remaining post-hoc comparisons were not statistically significant. The trend towards an interaction effect may suggest a crossover interaction by which the LR infants may increase their number of fixations per second from 11 to 16 months, whereas HR infants may remain consistent in their active scanning composite across age (see Figure 12). Conducting 2x2 repeated measures ANOVA on the extent of active scanning separately for static and dynamic tasks did not yield any significant main or interaction effects of age or risk.

Attention to figure vs. background (static tasks only). Although the *a priori* figure versus background attentional composite (using all tasks) did not yield any significant results from a 2x2 repeated measures ANOVA, examination of the *data-driven* composite calculated using only static tasks yielded significant findings. The 2x2 repeated measures ANOVA was conducted on the ratio of looking duration to figures relative to the background during static tasks and showed a main effect of age ($F(1,77) = 8.08$, $p < .01$, partial η^2 of age = 0.10, observed power = 0.80, Cohen's $d = 0.61$) and a trending interaction effect of age and risk ($F(1,77) = 3.43$, $p = .07$, partial η^2 of interaction = 0.04, observed power = 0.45). Post-hoc analyses showed one statistically significant comparison between LR infants' composite scores at 11 and 16 months ($t(35) = -3.01$, $p < 0.01$), but the remaining post-hoc comparisons did not reach statistical significance. Thus, the marginally significant cross-over interaction effect may suggest that LR infants increase the ratio of attention to figures relative to the background from 11 months (M = 6.07, SD = 3.14) to 16 months (M = 8.43, SD = 4.47), whereas HR infants may not show this same growth from 11 months to 16 months (see Figure 13).

Attention to figure vs. background (dynamic tasks only). The 2x2 repeated measures ANOVA on the ratio of attention to figures relative to the background during dynamic tasks did not yield any significant main or interaction effects.

Maintenance of attention. A 2x2 repeated measures ANOVA was conducted on the average ratio of attention to the first half relative to the second half of dynamic video presentations. Results indicated a trending main effect of age on the maintenance of attention composite ($F(1,56) = 2.82$, $p < .10$, partial η^2 of age = 0.05, observed power = 0.38, Cohen's d = 0.25). No main effect or interaction with risk status was observed. These findings did not reach statistical significance, so this may tentatively suggest that infants showed an increased ratio of attention maintenance from 11 months (M = 2.26, SD = 1.43) to 16 months of age (M = 2.87, SD = 3.14) regardless of risk status.

Remaining attentional composites. No significant main or interaction effects of risk status or age were found for 2x2 repeated measures ANOVA on the remaining *a priori* visual attention composites: attention to figure vs. background, attention to novelty, attention to static vs. dynamic stimuli and attention to social vs. nonsocial stimuli.

Summary of results. Collectively, these analyses provide some support for trending risk by age interactions regarding the active scanning composite (across all tasks) and the attention to figure vs. background composite (limited to static tasks). Unlike HR infants, LR infants may increase their scores in these two attentional processes from 11 to 16 months. In addition, regardless of risk status, it appeared that infants may increase their overall proportion of looking (as measured across all tasks or limited to static tasks) with age. Infants may also increase their maintenance of attention composite score from 11 to 16 months, but this trend did not reach statistical significance and should be interpreted with caution. Furthermore, given that 13 measures were analyzed, a Bonferroni correction would yield an adjusted significance value of 0.004. Therefore, interpretations of trending findings (of ≤ 0.10) are highly tentative.

3.6 ATTENTIONAL COMPOSITES AS PREDICTORS OF ATYPICAL DEVELOPMENT AND ASD DIAGNOSIS

Using the outcome classification criteria at 24, 36 and or 48 months of age, infants were classified into one of the following outcome groups: ASD, NT or TD. The sample consisted of 10 ASD, 7 NT and 68 TD infants (for descriptive statistics of attentional composites by outcome group, see Table 14 for 11-month data and Table 15 for 16-month data). The possibility of high-functioning and low-functioning subgroups within the ASD outcome group was explored using Mullen DQ at 36 months. The mean 36-month Mullen DQ of the ASD group was 78.25, suggesting a skewed distribution consisting of mostly low-functioning individuals so ASD subgroups were not identified in the sample (see Figure 14).

The following analyses consisted of binary logistic regression to predict the probability of (1) *atypical development* (which was defined as childhood outcome classification as ASD or NT) and (2) *ASD diagnosis*, from *a priori* and *data-driven* visual attention composite scores measured at 11 and 16 months. To predict *atypical development*, a binary logistic regression analysis was conducted using predictors of risk status and attentional composites with less than 20% missing data. *Atypical development* referred to infants later classified as ASD and NT, whereas the comparison group consisted of TD infants. Attentional composites with substantial missing data were excluded from logistic regression analyses to maintain sufficient statistical power. The *a priori* attentional composites excluded from the regression model were: attention to social versus nonsocial stimuli, maintenance of attention and attention to novelty. Given the exploratory nature of infant visual attention composites, logistic regression was conducted using a direct entry method to predict atypical development from predictors of risk status, proportion of looking, attention to static versus dynamic stimuli, active scanning and attention to figure versus background. Stepwise removal of non-significant predictors to improve overall model prediction success were attempted as needed. Separate analyses were completed at 11 and 16 months of age. As described in the previous analyses related to the creation and validation of the visual attention composites, potential issues of multicollinearity were addressed.

A second binary logistic regression analysis was conducted to predict *atypical development* using risk with the aforementioned attentional composite predictors substituted for their *data-driven* counterparts (e.g., static tasks only, dynamic tasks only) if applicable. That is, the *data-driven* approach utilized the following predictors: risk, proportion of looking during static tasks, proportion of looking during dynamic tasks, active scanning during static tasks, active scanning during dynamic tasks, attention to figure versus background during static tasks, attention to figure versus background during dynamic tasks, and attention to static versus dynamic stimuli. After all predictors were added, non-significant predictors were removed in stepwise fashion until maximum overall model prediction success was achieved. Again, separate analyses were conducted at 11 and 16 months. Multicollinearity issues were addressed in the previous section dedicated to creating and validating the attentional composites.

Lastly, binary logistic regression was conducted to predict an *ASD diagnosis* from the predictors of risk status and the aforementioned *a priori* visual attention composites that maximized the sample size of the analysis. The group of infants later diagnosed with ASD was the outcome group of interest, and the comparison group consisted of infants later classified as NT or TD. Similarly, this analysis was followed by its corresponding *data-driven* approach which included applicable *data-driven* attentional composites to predict *ASD diagnosis*. Separate analyses were conducted at 11 and 16 months.

Logistic regression at 11 months. Risk status and the attentional composites at 11 months listed below were considered for logistic regression equations predicting *atypical development* and *ASD diagnosis*. This *a priori* approach utilized predictors of:

1. Genetic risk status (*risk)*
2. Proportion of looking composite (*proplook*)
3. Attention to figure vs. background composite (*figback*)
4. Active scanning composite (*actscan*)
5. Attention to static vs. dynamic stimuli composite (*statdyn*)

Logistic regression was also conducted using a *data-driven* approach, which included predictors of risk and 11-month *data-driven* attentional composites for consideration in logistic regression equations to predict *atypical development* and *ASD diagnosis:*

1. Genetic risk status (*risk)*
2. Proportion of looking during static tasks (*lookstat)*
3. Proportion of looking during dynamic tasks (*lookdyn)*
4. Attention to figure vs. background during static tasks (*figstat)*
5. Attention to figure vs. background during dynamic tasks (*figdyn)*
6. Active scanning during static tasks (*activestat)*
7. Active scanning during dynamic tasks (*activedyn)*
8. Attention to static vs. dynamic stimuli (*statdyn)*

A summary table of these *a priori* and *data-driven* predictors considered for binary logistic regression is provided in Table 16.

Logistic regression using a priori composites to predict atypical development. The logistic regression analysis was conducted considering risk and the visual attention composites listed previously for the *a priori* approach to predict *atypical development.* Results indicated the following prediction equation was statistically significant:

$$log(p/1\text{-}p) = b0 + b1{*}risk + b2{*}proplook + b3{*}figback + b4{*}actscan + b5{*}statdyn$$

Therefore, compared to a constant-only model, the statistical significance of this model supports that this set of predictors reliably distinguished *atypical development* from *typical development* (chi squared = 10.86, $p = 0.05$, $df = 5$, log-odds = 69.20). However, these results are interpreted with caution due to the small sample size. Overall prediction success of the model was 81.3% (*typical development* = 98.4%, *atypical development* = 12.5%). Upon examination of the predictors in the equation, the ß value of *statdyn* was 0, indicating that *statdyn* was not contributing to the overall model. Logistic regression was repeated with the removal of the *statdyn* composite variable (see prediction equation below), which yielded improvement to the model fit.

*log(p/1-p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan*

This model was statistically significant compared to a constant-only model, meaning that this set of predictors reliably distinguished *atypical development* from *typical development* (chi squared = 12.55, $p < 0.05$, $df = 4$, log-odds = 72.07). The model's prediction success was 82.1% (*typical development* = 98.5%, *atypical development* = 17.6%). For more detailed information, including odds ratios of the predictors, see Table 17. Given the small sample sizes, odds ratios showed large confidence intervals that limit the interpretability of the model. No additional predictors were removed from the model because doing so worsened the overall prediction success of the model.

Logistic regression using data-driven composites to predict atypical development. Binary logistic regression was conducted considering risk and the attentional composites listed above (under the *data-driven* approach) to predict *atypical development.* The prediction equation was statistically significant:

*log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*figdyn + b6*activestat + b7*activedyn + b8*statdyn*

Thus, compared to a constant-only model, this set of predictors reliably distinguished *atypical development* from *typical development* (chi squared = 18.65, $p = 0.01$, $df = 8$, log-odds = 52.72). The model's overall prediction success was 83.6% (*typical development* = 96.6%, *atypical development* = 28.6%). Removal of non-significant predictors worsened the model's overall prediction success so results did not support alterations to the initial model (see Table 17 for odds ratios of predictors). However, odds ratios of the model and their confidence intervals demonstrated highly variable and/or extreme values that hinder interpretation of the model. Results were highly influenced by the small sample size of the outcome group of interest (ASD and NT infants).

Logistic regression using a priori composites to predict ASD diagnosis. Similarly, binary logistic regression analysis to predict *ASD diagnosis* was conducted utilizing predictors of risk and the previously listed *a priori* visual attention composites. Results indicated that the model was statistically significant compared to a constant-only model (chi squared = 13.22, $p < 0.05$, $df = 5$, log-odds = 43.05). Thus, the set of predictors illustrated in this prediction equation below reliably distinguished *ASD diagnosis* from the other infants:

*log(p/1-p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan + b5*statdyn*

Overall prediction success of this model was 90% (*NT+TD* = 100%, *ASD diagnosis* = 11.1%). Stepwise removal of two non-significant predictors (proportion of looking and attention to static versus dynamic stimuli, respectively) maintained overall model prediction success. Thus, the final statistically significant model (chi squared = 12.98, $p < 0.01$, $df = 3$, log-odds = 43.29) described by the prediction equation below reliably distinguished *ASD diagnosis* from the other infants:

*log(p/1-p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan + b5*statdyn*

Odds ratios and classification sample sizes are provided in Table 17. However, the limited sample of ASD infants and the resultant highly variable or extreme values indicated in the odds ratios hindered interpretation of the model.

Logistic regression using data-driven composites to predict ASD diagnosis. Another binary logistic regression analysis was conducted to predict *ASD diagnosis* considering predictors of risk and the attentional composites previously listed under the *data-driven* approach. Compared to a constant-only model, the analysis showed the model was statistically significant (chi squared = 15.27, $p = 0.05$, $df = 8$, log-odds = 35.20), supporting that the set of predictors in the below equation reliably distinguished *ASD diagnosis* from the other infants:

$$log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*figdyn + b6*activestat + b7*activedyn + b8*statdyn$$

The model's overall prediction success was 91.8% (*NT+TD* = 100%, *ASD diagnosis* = 25%). Testing consecutive removal of non-significant predictors produced models that maintained the same overall prediction success, so four predictors were removed, after which additional removal of a non-significant predictor worsened the model's prediction success. The prediction equation of the final model (that maintained identical prediction success) was as follows (chi squared = 14.57, $p < 0.01$, $df = 4$, log-odds = 41.94):

$$log(p/1-p) = b0 + b1*risk + b2*lookdyn + b3*activestat + b4*statdyn$$

It is important to note that odds ratios of the model and their confidence intervals demonstrated highly variable and/or extreme values that hinder interpretation of the model. Results are interpreted with caution. For more detailed information, such as odds ratios of predictors, see Table 16.

Logistic regression at 16 months. Predictors of risk status and the 16-month attentional composites of interest listed below were considered for entry into logistic regression equations to predict both *atypical development* and *ASD diagnosis*:

1. Genetic risk status (*risk)*
2. Proportion of looking composite (*proplook*)
3. Attention to figure vs. background composite (*figback*)
4. Active scanning composite (*actscan*)

5. Attention to static vs. dynamic stimuli composite (*statdyn*)

This approach utilized *a priori* attentional composites, whereas a second *data-driven* approach was also used to predict *atypical development* and *ASD diagnosis.* With this *data-driven* approach, the proportion of looking, attention to figure vs. background and active scanning composites were substituted for their two *data-driven* counterparts (e.g., proportion of looking during static tasks and proportion of looking during dynamic tasks). As such, the following predictors at 16 months were considered for entry into logistic regression equations predicting *atypical development* and *ASD diagnosis* in a second set of analyses:

1. Genetic risk status (*risk)*
2. Proportion of looking during static tasks (*lookstat)*
3. Proportion of looking during dynamic tasks (*lookdyn)*
4. Attention to figure vs. background during static tasks (*figstat)*
5. Attention to figure vs. background during dynamic tasks (*figdyn)*
6. Active scanning during static tasks (*activestat)*
7. Active scanning during dynamic tasks (*activedyn)*
8. Attention to static vs. dynamic stimuli (*statdyn)*

Logistic regression using a priori composites to predict atypical development. The logistic regression analysis was conducted with the aforementioned predictors of risk and attentional composites at 16 months of age to predict *atypical development.* The analysis resulted in a statistically significant model compared to a constant-only model (chi squared = 14.38, $p < 0.05$, $df = 5$, log-odds = 67.90). This finding supports that this set of risk and attentional composites distinguished *atypical development* from *typical development*. Results indicated the following prediction equation for *atypical development*:

$$log(p/1-p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan + b5*statdyn$$

Overall prediction success of the model was 86.1% (*typical development* = 96.8%, *atypical development* = 47.1%). However, given the small sample size, odds ratios showed very large confidence intervals and/or extreme values that made interpretation of the model difficult. Sample sizes and odds ratios are described in Table 18. Removal of non-significant predictors yielded either a decrease in the model's prediction success or a non-significant model fit with the remaining predictor set, so no alterations were made to the model.

Logistic regression using data-driven composites to predict atypical development. Binary logistic regression using risk and the attentional predictors outlined in the previously mentioned *data-driven* approach was conducted to predict *atypical development.* Results indicated that the following prediction equation was statistically significant, indicating that this set of predictors reliably distinguished *atypical development* from *typical development* (chi squared = 23.27, $p < 0.01$, $df = 8$, log-odds = 50.88).

$$log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*figdyn + b6*activestat + b8*statdyn$$

Overall prediction success of the model was 82.2% (*typical development* = 93.1%, *atypical development* = 40.0%). Consecutive removal of non-significant predictors in a backwards stepwise fashion yielded improvement in overall model fit with the removal of two predictors (active scanning during static tasks and figure vs. background during dynamic tasks). This final regression prediction equation that maximized prediction success (chi squared = 21.59, $p < 0.01$, $df = 6$, log-odds = 52.57) is illustrated by:

$$log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*activestat + b6*statdyn$$

Overall prediction success of this final model was 83.6% (*typical development* = 94.8%, *atypical development* = 40.0%; see Table 17 for model details). However, odds ratios were highly variable in their values and confidence intervals, which impacted interpretability of the model. These tentative results with a small sample size were interpreted with caution.

Logistic regression using a priori composites to predict ASD diagnosis. Conducting a binary logistic regression analysis to predict *ASD diagnosis* with possible predictors of risk and the 16-month *a priori* visual attention composites with maximal sample sizes (proportion of looking, active scanning, attention to figure versus background, and attention to static versus dynamic stimuli) yielded a statistically significant model (chi squared = 18.20, $p < 0.01$, $df = 5$, log-odds = 41.81) compared to a constant-only model. The following prediction equation shows *risk* and these attentional composites to be a significant set of predictors for *ASD diagnosis*:

$$log(p/1\text{-}p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan + b5*statdyn$$

The model's overall prediction success was 89.9% (*NT+TD* = 100%, *ASD diagnosis* = 20%). Stepwise removal of one non-significant predictor maintained overall model fit, so this predictor (attention to static versus dynamic stimuli) was removed for the final model, as shown in the following prediction equation:

$$log(p/1\text{-}p) = b0 + b1*risk + b2*proplook + b3*figback + b4*actscan$$

This final analysis yielded a statistically significant result (chi squared = 18.20, $p < 0.01$, $df = 4$, log-odds = 41.81), indicating that this set of predictors distinguished infants with an *ASD diagnosis* from the other (NT + TD) infants. It should be noted that the model is difficult to interpret due to the small sample of ASD infants and the highly variable odds ratio values and/or confidence intervals. For sample sizes and odds ratios, see Table 18.

Logistic regression using data-driven composites to predict ASD diagnosis. In addition, binary logistic regression was conducted to predict *ASD diagnosis* using the *data-driven* approach which considered predictors of risk, *data-driven* attentional composites and attention to static versus dynamic stimuli. Relative to a constant-only model, the analysis yielded a statistically significant model (chi squared = 25.17, $p < 0.01$, $df = 8$, log-odds = 25.30). This set of predictors illustrated in the prediction equation below reliably distinguished *ASD diagnosis* from other infants:

$$log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*figdyn + b6*activestat + b7*activedyn + b8*statdyn$$

Overall prediction success was 89.0% (*NT+TD* = 95.4%, *ASD diagnosis* = 37.5%). After consecutively removing non-significant predictors and retesting the model in backwards stepwise fashion, results indicated that overall model fit was improved by the removal of two predictors (active scanning during static tasks and active scanning during dynamic tasks). Removal of a third variable decreased overall prediction success, so no additional alterations were made to the model. The final model was statistically significant (chi squared = 24.92, $p < 0.001$, $df = 6$, log-odds = 25.55), which may suggest that the set of predictors described in the equation below distinguished *ASD diagnosis* from the other (NT+TD) infants:

$$log(p/1-p) = b0 + b1*risk + b2*lookstat + b3*lookdyn + b4*figstat + b5*figdyn + b6*statdyn$$

However, it is difficult to interpret the model given the large confidence intervals and/or extreme values of the odds ratios. Results are highly influenced by the limited sample of ASD infants. The final model yielded an improved overall prediction success of 90.4% (*NT+TD* =

96.9%, *ASD diagnosis* = 37.5%). For classification sample sizes and odds ratios of predictors, see Table 18.

Summary of results. Using binary logistic regression, 11-month risk and attentional composites showed limited predictive success for later atypical development and/or ASD diagnosis in childhood. Prediction success across 11-month models remained below 30%; however, 16-month risk and attentional composites showed higher prediction success for identifying later atypical developmental outcomes and/or ASD diagnosis. Some models accurately identified approximately 47% of atypical developmental outcome cases and 38% of ASD cases. Although these models included attentional composite predictors, results indicated risk to be the only *significant* predictor of later atypical development or ASD diagnosis since none of the attentional composites showed odds ratios with confidence intervals that did not include 1.0. Therefore, the possible clinical implications of attentional composites based on the present study are tentative and should be interpreted with caution. Furthermore, results are highly tentative due to the limited sample sizes of ASD and NT infants (10 and 7, respectively), which likely contributed to the highly variable confidence intervals and/or extreme values of the odds ratios. Consequently, interpretability of the models was hindered.

3.7 INFANT ATTENTIONAL COMPOSITES AS PREDICTORS OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS

Multiple linear regression was conducted in the following analyses to address the extent to which infant visual attention composites were predictive of later childhood intellectual functioning as measured by 36-month Mullen developmental quotient (DQ). This outcome assessment age minimized missing data compared to the other two outcome ages (24 and 48 months), so 36-month Mullen DQ was the preferable outcome measure to maximize the sample size and statistical power of analyses. Predictors consisted of risk status and attentional composites with less than 20% missing data to maximize the sample size and maintain sufficient statistical power. Attentional composites considered for multiple regression were: proportion of looking, attention to static versus dynamic stimuli, active scanning and attention to figure versus background. *A priori* attentional composites and the *data-driven* composite counterparts (which were calculated based only on static tasks or only dynamic tasks) were tested separately. As described in the previous section validating the visual attention composites, there were no substantial issues with multicollinearity. Since these analyses were exploratory in nature, there was not a pre-determined order of entry for predictor variables so a direct method was used in the analyses and followed by stepwise removal of non-significant predictors. Given the small infant samples, results are interpreted with caution. Independent analyses were conducted at 11 and 16 months of age.

Multiple linear regression using a priori composites at 11 months. Multiple linear regression was conducted with predictor variables of risk, proportion of looking, attention to static versus dynamic stimuli, active scanning and attention to figure versus background at 11 months to predict Mullen DQ at 36 months. This set of variables predicting 36-month Mullen DQ yielded an adjusted R^2 of 0.23 ($F(5,61) = 4.95$, $p < 0.01$). The predictor, active scanning, had the lowest non-significant standardized regression coefficient ($\beta = .006$, $p = 0.96$) and was removed from the regression. Conducting a subsequent regression analysis with the remaining predictors produced an adjusted R^2 of 0.24 ($F(4,62) = 6.29$, $p < 0.001$). Proportion of looking was identified as holding the lowest nonsignificant regression coefficient (β = .06, p = 0.61) and was thus removed from the analysis and the regression analysis was repeated. The regression consisting of the remaining three predictors yielded an adjusted R^2 of 0.25 (F(3,63) = 8.39, p < 0.001). Again, of these three predictors, the predictor with the lowest non-significant regression coefficient (attention to static versus dynamic stimuli; β = -0.09, p = 0.43) was removed from the analysis and the regression analysis was conducted with two predictors. This regression analysis yielded an adjusted R^2 of 0.25 (F(2,67) = 12.74, p < 0.001). Of these two predictors, attention to figure versus background remained statistically non-significant (β = .06, p = 0.61), which may suggest that none of the visual attention composites improved the model fit. A final regression analysis of risk predicting 36-month Mullen DQ was conducted, yielding a model with R = 0.50, R^2 = 0.25 and adjusted R^2 = 0.24 (F(1,69) = 23.30, p < 0.001). As shown in Table 19, risk (β = -0.50, p < 0.001) explained 25.2% of the variance in 36-month Mullen DQ.

Multiple linear regression using data-driven composites at 11 months. Multiple linear regression was also conducted to predict 36-month Mullen DQ using risk and the following *data-driven* composites: proportion of looking during static tasks, proportion of looking during dynamic tasks, attention to figure versus background during static tasks, attention to figure versus background during dynamic tasks, active scanning during static tasks, active scanning during dynamic tasks, and attention to static versus dynamic stimuli. This set of variables predicting 36-month Mullen DQ yielded an adjusted R^2 of 0.20 (F(8,56) = 3.03, p < 0.01). The predictor with the lowest non-significant standardized regression coefficient was attention to figure versus background during dynamic tasks (β = -0.007, p = 0.95), so it was removed from the regression. The regression analysis was then repeated and this process of progressively removing nonsignificant predictors continued until only statistically significant predictors remained. The final regression analysis consisted only of risk status predicting 36-month Mullen DQ with R = 0.50, $R^2 = 0.25$ and adjusted $R^2 = 0.24$ ($F(1,69) = 23.30$, $p < 0.001$) as found in the previous analysis using *a priori* composites (for beta weights, see Table 19). Results may indicate that visual attention composites were not statistically significant predictors of 36-month Mullen DQ using either the *a priori* or *data-driven* approach at 11 months.

Multiple linear regression using a priori composites at 16 months. As conducted at 11 months, multiple linear regression was also conducted with predictor variables of risk, proportion of looking, attention to static versus dynamic stimuli, active scanning and attention to figure versus background at 16 months to predict Mullen DQ at 36 months. This set of predictors for 36-month Mullen DQ yielded an adjusted R^2 of 0.29 ($F(5,61) = 6.47$, $p < 0.001$). Of the predictors, attention to static versus dynamic stimuli had the lowest non-significant standardized regression coefficient ($\beta = .002$, $p = 0.98$) and was removed from the analysis. Conducting multiple linear regression with the remaining predictors yielded an adjusted R^2 of 0.31 ($F(4,65) = 8.57$, $p < 0.001$). The next variable with the lowest nonsignificant regression coefficient was proportion of looking ($\beta = .14$, $p = 0.29$). Therefore, the proportion of looking predictor was removed from the analysis and the regression analysis was repeated. The regression consisting of the remaining three predictors yielded an adjusted R^2 of 0.30 ($F(3,66) = 11.02$, $p < 0.001$). The subsequent predictor with the lowest non-significant regression coefficient (active scanning; $\beta = 0.06$, $p = 0.55$) was removed from the analysis and the analysis was conducted again. This final regression analysis yielded an R of 0.57, R^2 of 0.33 and adjusted R^2 of 0.31 ($F(2,67) = 16.50$, $p < 0.001$) with risk and attention to figure versus background predicting 36-month Mullen DQ. This pair of predictors shared 3.7% of the explained variance but uniquely explained 29.3% of the variance in 36-month Mullen DQ. Results indicated that risk ($\beta = -0.48$, $p < 0.001$) was a stronger predictor relative to the attention to figure versus background composite ($\beta = 0.25$, $p = 0.01$; see Table 19).

Multiple linear regression using data-driven composites at 16 months. Multiple linear regression was then conducted with predictors of risk and attentional composites (calculated separately for static tasks and dynamic tasks as applicable) at 16 months to predict Mullen DQ at 36 months. This set of predictors for 36-month Mullen DQ yielded an adjusted R^2 of 0.29 ($F(8,58) = 4.38$, $p < 0.001$). Of the eight predictors, proportion of looking during static tasks had the lowest non-significant standardized regression coefficient ($\beta = .01$, $p = 0.97$) and was removed from the analysis. Conducting multiple linear regression with the remaining predictors yielded an adjusted R^2 of 0.30 ($F(7,59) = 5.10$, $p < 0.001$). A stepwise removal of the predictor with the lowest non-significant standardized regression coefficient until only significant predictors remained yielded a final regression model with two predictors. The final regression analysis consisted of risk and attention to figure versus background during static tasks predicting 36-month Mullen DQ with an R of 0.54, R^2 of 0.29 and adjusted R^2 of 0.27 ($F(2,64) = 13.22$, $p < 0.001$). As shown in Table 19, risk ($\beta = -0.47$, $p < 0.001$) was a stronger predictor compared to the attention to figure versus background during static tasks composite ($\beta = 0.20$, $p = 0.06$). The attentional composite was marginally significant, so results were interpreted with caution. Based on this finding, the pair of predictors may share 3.6% of the explained variance but may uniquely explain 25.4% of the variance in 36-month Mullen DQ.

Summary of results. At 11 months, risk was the only significant predictor of later 36-month Mullen DQ. Results did not support any 11-month attentional composites as significant predictors of later intellectual functioning. Although interpretations are limited by the overall sample size of infant-siblings in the present study, regression analyses using 16-month predictors may provide some support for risk and the attention to figure versus background composites (as calculated across all tasks or limited to static tasks) as early predictors of later Mullen DQ. It should be noted that the *data-driven* attentional composite (that was limited to static tasks) was only marginally significant and should be interpreted with caution.

3.8 INFANT DEVELOPMENTAL QUOTIENTS AS PREDICTOR OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS

For this final set of analyses, multiple linear regression was conducted to address the extent to which infant Mullen DQ was predictive of later childhood intellectual functioning (using 36-month Mullen DQ) in relation to the statistically significant infant predictors found in the previous regression analyses. Separate analyses were conducted at 11 and 16 months. Thus, at 11 months, predictors consisted of risk and 11-month Mullen DQ. No visual attention composites were included since none were found to be statistically significant predictors of 36-month Mullen DQ in the prior regression analyses. At 16 months, predictors consisted of risk, attention to figure versus background (an *a priori* composite), attention to figure versus background during static tasks (a *data-driven* composite) and 16-month Mullen DQ. The *a priori* and *data-driven* composites were tested separately to avoid collinearity issues.

Multiple linear regression at 11 months. Since the prior regression analyses did not indicate that visual attention composites (calculated using the *a priori* or *data-driven* approaches) were significantly predictive of 36-month Mullen DQ, attentional predictors were excluded from the analysis. Multiple linear regression was conducted using predictors of risk (which was shown to be a statistically significant predictor in the prior regression analysis) and 11-month Mullen DQ to predict 36-month Mullen DQ (for beta weights table, see Table 19). The analysis showed that this pair of predictors for 36-month Mullen DQ yielded an R of 0.60, R^2 of 0.35 and adjusted R^2 of 0.33 ($F(2,65) = 17.82$, $p < 0.001$). Results indicated that each predictor was statistically significant, with risk ($\beta = -0.41$, $p < 0.001$) being a stronger predictor of 36-month Mullen DQ than 11-month Mullen DQ ($\beta = 0.34$, $p < 0.01$). Risk and 11-month Mullen DQ shared 8.9% of the explained variance but uniquely explained 26.5% of the variance in 36-month Mullen DQ.

Multiple linear regression using a priori composites at 16 months. Multiple linear regression was conducted with predictors of risk, the attention to figure versus background composite and Mullen DQ at 16 months to predict 36-month Mullen DQ. Other attentional composites were excluded from the analysis because they were not found to be significant predictors in the final model derived in the prior regression analyses. This set of three predictors for 36-month Mullen DQ yielded a model with an adjusted R^2 of 0.47 ($F(3,59) = 19.56$, $p < 0.001$). Upon examination of the individual predictors, one predictor (attention to figure versus background; $\beta = 0.09$, $p = 0.36$) was not a statistically significant predictor. This predictor was thus removed from the analysis and the regression analysis was conducted again with the remaining pair of predictors. This final regression model consisted of risk and 16-month Mullen DQ as predictors of 36-month Mullen with an R of 0.70, R^2 of 0.49 and adjusted R^2 of 0.47 ($F(2,61) = 29.07$, $p < 0.001$). Results indicated that these predictors shared 11% of the explained variance but uniquely explained 38.0% of the variance in 36-month Mullen DQ. Mullen DQ at 16 months ($\beta = 0.47$, $p < 0.001$) was a stronger predictor of later Mullen DQ than risk status ($\beta = -0.43$, $p < 0.001$; for beta weights table, see Table 19).

Multiple linear regression using data-driven composites at 16 months. Similarly, multiple linear regression was conducted to predict 36-month Mullen DQ using predictors of risk, 16-month Mullen DQ and the attention to figure versus background during static tasks composite. Other *data-driven* attentional composites were not considered since they were not significant predictors in the previous regression analyses. This set of predictors yielded an adjusted R^2 of 0.44 ($F(3,60) = 17.78$, $p < 0.001$). The attention to figure versus background during static tasks composite ($\beta = 0.11$, $p = 0.26$) was identified as the only statistically non-significant predictor, so this predictor was removed. Therefore, since neither the *a priori* or *data-driven* attentional composites were included in the final model across the 16-month regression analyses, results yielded the same final regression model of risk and 16-month Mullen DQ predicting 36-month Mullen DQ from the previous regression analysis using the *a priori* approach (see Table 19 and prior section, *multiple linear regression using a priori attentional composites at 16 months*).

Summary of results. Collectively, results may suggest some similarities in early predictors of 36-month Mullen DQ across infancy. Risk and 11-month Mullen DQ may be significant predictors of later Mullen DQ at 36 months. At 16 months, the figure vs. background attentional composite (calculated using the *a priori* approach or limited to static tasks only) was not supported as a significant predictor after 16-month Mullen DQ was considered in the model. Thus, a similar result emerged across age, in which 16-month Mullen DQ and risk were the only predictors of later childhood Mullen DQ. However, these tentative results are limited by the small infant-sibling sample of the present study and must be interpreted with caution.

4.0 DISCUSSION

The present study explored the utility of calculating visual attention composites for identifying attentional differences and predicting later childhood intellectual functioning among infants with and without heightened genetic risk for ASD at 11 and 16 months of age. The primary aims of the study were to: (1) investigate infants' general attentional abilities (as measured by attentional composites) based on risk status (HR vs. LR) across 11 and 16 months of age; (2) explore attentional composites as predictors of later childhood outcome classifications (e.g., ASD and NT); (3) examine the relationships between visual attention composites and later childhood functioning; and lastly, (4) assess the predictive value of these attentional composites for later functioning relative to infant DQs.

Attentional differences across age and risk status are summarized and interpreted in the context of current conceptualizations of ASD and its emergence in early development. This is followed by a discussion of findings that investigated infant visual attention composites and/or DQs as predictors of later childhood outcome classification (e.g., ASD diagnosis) and later intellectual functioning (as measured by Mullen DQ). The clinical implications of these findings are explored.

4.1 VISUAL ATTENTION ACROSS 11 AND 16 MONTHS

In examining HR and LR infants' visual attention composite scores across 11 and 16 months of age, the present study may suggest several interpretations regarding the early development of visual attention. Given the limited sample size, each result is followed by a tentative interpretation with respect to extant literatures and current theory.

Risk by age interaction effects in visual attention development. First, trending interactions of age and risk were found for the active scanning composite and the attention to figure versus background during static tasks composite. Since these results did not reach statistical significance, findings are interpreted with caution. The same pattern appeared to emerge across both composites, in which LR infants may demonstrate increases in these attentional skills from 11 to 16 months but HR infants may not. An increase in active scanning may translate to an increase in the number of fixations per second with age, whereas increased attention to figure versus background during static tasks composite scores may suggest that LR infants show a greater ratio of attention to figures relative to the background from 11 to 16 months. Broadly, these attentional patterns may suggest that LR infants are becoming more skilled at distributing their attention and attending a greater proportion of time to relevant stimulus areas from 11 to 16 months than HR infants.

Implications for active scanning development. The trending finding that HR infants may not display increased active scanning from 11 to 16 months would be consistent with previous findings of attentional disengagement difficulties in HR infants (Ibanez et al., 2008) and infants later diagnosed with ASD (Elsabbagh et al., 2013). Since this composite was calculated across diverse static and dynamic eye-tracking tasks, this result may suggest that by 16 months, HR infants may display a general attentional pattern to visual stimuli that differs from LR infants. Fewer fixations per second across tasks in HR infants by 16 months is supported by prior work showing disengagement difficulties among HR infants and those later diagnosed with ASD under varied task conditions, including parent-child interactions (Ibanez et al., 2008) and basic visual attention experiments (Elsabbagh et al., 2013). The tentative lack of increase in active scanning with age among HR infants could be indicative of an attentional delay, which may or may not persist across development. Since HR infants are at heightened risk for language and other developmental delays (for review, see Rogers, 2009), it is possible that HR infants may improve in this attentional skill later in infancy, such that this potential trend reflects an attentional *delay* rather than an attentional *deficit.* Alternatively, particularly for infants later diagnosed with ASD, difficulties disengaging and re-engaging attention may persist into childhood given findings that children with ASD aged 3-7 years continued to show lower rates of disengagement from stimuli (i.e., “sticky attention”; Landry & Bryson, 2004). More generally, there is substantial research in ASD supporting visual attention differences across the lifespan (Chawarska et al., 2010; Elison et al., 2012; Frazier et al., 2016; Landry & Bryson, 2004; Sasson et al., 2011; Swetteham et al., 1998; Zwaigenbaum et al., 2005).

Although interaction effects did not reach statistical significance, possible ramifications of less scanning (i.e., fewer fixations per second) in HR 16-month-olds can be considered. It is theorized that prolonged looking infants are more likely to remain visually fixated on a stimulus (Reynolds et al., 2013) and may spend more time in the attention termination phase during which infants are looking but not actively engaged or scanning (Colombo, 2002). Furthermore, this looking behavior pattern is related to poorer visual recognition performance (Colombo, 2002). Thus, an early difference in attentional disengagement may lead HR infants to process information less effectively than infants who are more skilled at disengaging attention and scanning for more information. Furthermore, these infants may show different behavioral responses, such that they explore their environments differently. For example, in a study of infants with FXS, a longer latency to disengage attention in 12-month-olds was significantly associated with higher severity of ASD symptomatology (Roberts et al., 2012). In addition, 12-month-old infants' disengagement difficulties predicted ASD symptoms and the number of social-communicative impairments of children at two years of age (Landry & Bryson, 2004).

Implications for attention to figures versus background. Similar to active scanning development, when viewing static tasks, LR infants demonstrated an increase in the ratio of their attention to relevant figures relative to background areas from 11 to 16 months but HR infants did not. Although this trending interaction did not reach statistical significance in the present study, it is consistent with reduced attention to the figures of interest shown in ASD populations, starting as early as infancy (Bernabei et al., 1998; Osterling & Dawson, 1994; Maestro et al., 1999; Shic et al., 2014; for face processing review, see Webb et al., 2016; Zwaigenbaum et al., 2005). For example, as early as 6 months of age, infants later diagnosed with ASD had reduced attention to the person of a naturalistic scene (Chawarska et al., 2013; Shic et al., 2014). In addition, compared to typical children, children with ASD tend to orient less to faces (Bernabei et al., 1998; Chawarska et al., 2013; Osterling & Dawson, 1994; Maestro et al., 1999; for face processing review, see Webb et al., 2016; Zwaigenbaum et al., 2005). Results may suggest that HR infants distribute their attention to static stimuli differently than LR infants. By attending less to relevant figures (e.g., people, faces or objects of interest) and more to background areas, HR infants may process different information than LR infants and may be less effective at learning from the salient cues in the environment.

It should be noted that this trending attentional pattern was specific to the composite calculated using only static tasks. The fact that this result was not also shared by the overall attention to figure versus background composite or the same composite calculated using only dynamic tasks may indicate that stimulus characteristics may be particularly influential in HR infants' distribution of attention between figures and background. It is possible that motion and audiovisual cues that are present in dynamic eye-tracking tasks may reduce attentional differences between HR and LR infants. Motion and audiovisual synchrony would provide salient cues for the most relevant areas for attention. This possible conclusion is consistent with previous research that failed to find attentional differences to facial movements in infants later diagnosed with ASD at 7 or 14 months of age (Elsabbagh et al., 2014).

Again, it is unclear whether the trend between HR and LR infants in their ratio of attention to figures versus the background during static tasks may be indicative of an attentional *delay* or an attentional *deficit*. Other studies have found a gradual reduction in attention to the eye region (a highly relevant area for social-emotional cues; Jones & Klin, 2013) and to faces during live observation (Ozonoff et al., 2010) across the first few years of life, which highlights the importance of examining how visual attention may change across later infant development. Differing developmental trajectories in visual attention may be particularly beneficial in identifying HR infants without an ASD diagnosis from infants later diagnosed with ASD.

Age effects in visual attention development. Second, regardless of risk status, results may suggest some developments in visual attention abilities across the 11- and 16-month age points. Specifically, infants may increase their overall proportion of looking during eye-tracking tasks from 11 to 16 months of age. Results were also consistent when the proportion of looking composite was limited to performance during only static tasks (meaning dynamic task performance was excluded). Lastly, findings may suggest an increase in their maintenance of attention composite scores from 11 to 16 months, meaning infants may show a higher ratio of attention to the first half of dynamic video presentations relative to the second half across age.

Implications for attentional development in proportion of looking. Given that the eye-tracking tasks included in the present study use complex stimuli (i.e., dynamic complex naturalistic scenes, faces, detailed objects and dot patterns), it is not surprising that results may support an overall larger proportion of looking from 11 to 16 months. Such a finding is consistent with previous research indicating a decrease in infants' attention to simple objects and an increase in infants' attention to more complex objects with age (Ruff & Saltarelli, 1993). Longer looking is theorized in the typical infant literature to reflect infants using sustained attention skills for complex stimuli that need further processing (Reynolds et al., 2013).

Implications for attention maintenance across early development. An increased ratio of attention to the first half of video presentations relative to the second half may suggest that infants demonstrate a larger decrement in looking during the second half from 11 to 16 months of age regardless of risk status. Thus, infants may show greater habituation (e.g., systematic decline in looking) with age. As demonstrated in the extant literature on habituation, this finding may support that infants become more efficient at encoding the visual stimuli with age (Fantz, 1964).

4.2 ATTENTIONAL COMPOSITES AS PREDICTORS OF ATYPICAL DEVELOPMENT AND ASD DIAGNOSIS

Attentional composites considered as predictors (calculated using both *a priori* and *data-driven* approaches) were: proportion of looking, attention to figure versus background, active scanning, and attention to static versus dynamic stimuli. Results are interpreted with caution due to the limited sample sizes of ASD and NT infants (10 and 7, respectively). Broadly, analyses may support the predictive utility of *a priori* and *data-driven* attentional composites (in addition to risk status) as predictors of childhood outcomes of atypical development (i.e., ASD and NT) and ASD diagnosis. However, despite final models including attentional composite predictors, it should be noted that results did not show attentional predictors as statistically significant (because none of their odds ratios had confidence intervals that did not include 1.0). Only risk status showed odds ratios with confidence intervals that did not include 1.0, which suggests risk status was the only *significant* predictor of later atypical development or ASD diagnosis. Therefore, the possible implications of attentional composites of this exploratory study that follow are based on maximum prediction success rather than the statistical significance of the individual attentional predictors and are highly tentative.

At 11 months, the inclusion of most or all attentional composites (using the *a priori* or *data-driven* approach, respectively) and risk appeared to maximize prediction success for identifying atypical development. At 16 months, the inclusion of all attentional composites using the *a priori* approach and most *data-driven* composites with risk yielded a significant set of predictors with higher prediction success of children with atypical development than at 11 months. (Just two composites calculated using only dynamic tasks were excluded: active scanning and attention to figure versus background). However, models were difficult to interpret due to highly variable confidence intervals and/or extreme values of the odds ratios.

For predicting ASD diagnosis from 11 months, risk and three *data-driven* composites (proportion of looking during dynamic tasks, active scanning during static tasks, and attention to static versus dynamic stimuli) yielded a model with the highest predictive success (NT+TD = 100%, ASD = 25%). At 16 months, risk and most *data-driven* attentional composites yielded a model with the highest predictive success for later ASD diagnosis (NT+TD = 97%; ASD = 38%). (This model consisted of attention to static versus dynamic stimuli as well as both *data-driven* counterparts for proportion of looking and attention to figure versus background). It is important to note that interpretability of the models were hindered by the highly variable confidence intervals and/or extreme values of the odds ratios. Consequently, only risk status was a significant predictor of later ASD diagnosis. Tentatively, prediction success for ASD diagnosis appeared higher using 16-month data than 11-month data.

Collectively, results may suggest several key conclusions. First, the present study provides some tentative support that visual attention composites may be beneficial for predicting later childhood outcomes and ASD diagnosis. Second, data from 16 months may yield more successful prediction models for atypical development and ASD diagnosis than 11-month data. Third, multiple calculation methods for the visual attention composites (i.e., *a priori* and *data-driven* approaches) may be helpful for predicting later development but each approach tentatively illustrated a unique benefit. Upon further examination of the 16-month data (since it yielded higher predictive success than the younger age), both approaches may have comparable predictive utility; however, the *a priori* approach seemed more successful at predicting atypical development, whereas the *data-driven* approach appeared better at predicting ASD diagnosis.

Implications for attentional trends associated with atypical development and ASD diagnosis are briefly proposed based on these two prediction models.

Predictive utility of visual attention composites. The present study suggests that risk and visual attention composites as a set may be useful predictors of both atypical development and ASD diagnosis, but conclusions are highly tentative based on the limited sample of ASD and NT infants. Additional research is needed to explore these possible interpretations. These tentative findings may provide some preliminary support for the creation of visual attention composites as potentially beneficial means of reducing the high variability in infant looking behavior that is typically influenced by various moment-to-moment factors of individual tasks, including stimulus complexity, stimulus type (e.g., static or dynamic) and infant mood. Thus, the predictive utility of visual attention composites in the present study may support how measuring a combination of attentional processes across diverse eye-tracking task may be advantageous over using a singular attentional measure like proportion of looking or focusing on individual task performance.

Thus, although exploratory and limited in sample size, the present study may provide some support that the utility of visual attention composites for identifying ASD in childhood found in a previous study (Frazier et al., 2016) may be applied to earlier developmental periods, specifically infancy. Although Frazier and colleagues' (2016) ARI composite yielded higher diagnostic accuracy (with area under the curve > 0.90), the present study was exploratory in nature but provides tentative and preliminary support for investigating visual attention composites in infant-sibling samples. Nonetheless, within the present study, some improvements in diagnostic accuracy may be possible using attentional composites from 16 months of age rather than 11 months. This may suggest that developmental trajectories in general visual attention abilities diverge in ASD and atypical development after the first year of life. Although models were difficult to interpret, tentative results of the present study may suggest follow-up studies to investigate early predictors within infant-siblings given the heterogeneity of infant looking behavior compared to older populations as well as the well-established heterogeneity found in HR infant samples (for review, see Rogers, 2009). Therefore, it seems possible to examine diagnostic accuracy for identifying ASD within infant-sibling samples using visual attention composites in future studies that can build off the present study by developing a visual attention battery for this aim and testing attentional composites in larger ASD samples. A more detailed discussion of the broad potential clinical implications continues in a later section (see *Clinical Implications*).

Implications for calculation methods of visual attention composites. Given the predictive abilities of visual attention composites found in the present study, it is important to note that similar tentative conclusions were reached using both calculation approaches tested: the *a priori* approach (which was based on the theoretical framework of aggregating diverse eye-tracking tasks) and the *data-driven* approach (which utilized results from principal-component analysis to provide statistical evidence for unique calculations of attentional composites based on stimulus type as static or dynamic). Furthermore, all four *a priori* attentional composites and all six *data-driven* composites considered as predictors were included in at least one of the final models for predicting atypical development and/or ASD diagnosis. This may suggest that all the attentional processes under investigation (e.g., proportion of looking, attention to figures versus background, active scanning and attention to static versus dynamic stimuli) could be relevant attentional skills for predicting typical and atypical developmental pathways. However, interpretations are made with caution due to the small sample size. Further research is needed to explore these possibilities.

More broadly, these findings may support the use of both *a priori* and *data-driven* approaches as methods of creating visual attention composites. Yet, each calculation approach may provide a unique strength in the present study. In considering the 16-month data which yielded highest predictive success for later outcomes, it appears that the *a priori* approach may show an advantage in predicting atypical development (with atypical development prediction success of 47%), whereas the *data-driven* approach may be more successful at predicting ASD diagnosis (with a prediction success of 38%). Although tentative, results may provide some limited support for these calculation approaches as means for quantifying general attentional abilities and predicting later developmental outcomes.

Visual attention patterns that predicted atypical development and ASD outcomes. Since the logistic regression results should be interpreted with caution because of the limited sample sizes of ASD and NT infants, the visual attention patterns associated with higher risk for (1) atypical development and (2) ASD diagnosis are broadly described based on interpretation of the direction of odds ratios from the most successful prediction model (between *a priori* and data-driven approaches) for each outcome of interest. It is important to note that odds ratios values were difficult to interpret given highly variable confidence intervals and/or extreme values, so interpretations of the 16-month data (which are described below since these appeared to yield higher prediction rates for later outcomes than 11-month data) are highly tentative and require follow-up studies.

The 16-month *a priori* approach appeared to support the highest prediction success for later childhood atypical developmental outcomes. Higher probability of atypical development may be associated with HR status and lower attentional scores across all four composites: proportion of looking, active scanning, attention to figure versus background, and attention to static versus dynamic stimuli. Overall, later atypical developmental outcomes may be associated with a smaller proportion of time attending to stimuli, fewer fixations per second, less attention to relevant figures relative to background areas and less attention to static relative to dynamic stimuli. Similarly, based on the 16-month *data-driven* model (since it had higher predictive success for ASD compared to the *a priori* approach), higher probability of an ASD diagnosis may be associated with HR status, greater proportion of looking during static tasks, smaller proportion of looking during dynamic tasks, lower ratios of attention to figures relative to the background (for both static tasks and dynamic tasks) and lower ratio of attention to static relative to dynamic stimuli.

As previously discussed (see subsections, *Implications for active scanning development* and *Implications for attention to figures versus background*), lower proficiency across attentional skills would be consistent with the extant literature's findings in clinical and/or ASD populations showing less attention to various stimuli and/or figures of interest (e.g., eyes or people) (Bernabei et al., 1998; Jones & Klin, 2013; Maestro et al., 1999; Osterling & Dawson, 1994; Ozonoff et al., 2010; for face processing review, see Webb, Neuhaus, & Faja, 2016; Zwaigenbaum et al., 2005) as well as "sticky attention" tendencies (Elsabbagh et al., 2013; Landry & Bryson, 2004). Furthermore, a tentative attentional trend regarding increased proportion of looking during static tasks' association with later ASD diagnosis may be indicative of prolonged looking behavior and more time spent in the attention termination phase, in which infants are looking but not actively attending to stimuli (as measured by HR deceleration; Colombo, 2002; Colombo et al., 2001; Roberts et al., 2012). In contrast, a different attentional pattern may emerge during presentation of dynamic stimuli due to specific stimulus characteristics, such audiovisual synchrony and motion influencing looking behavior. Collectively, these findings may provide some support for attentional differences in infancy and may suggest lower proficiency across attentional skills can be predictive of atypical developmental outcomes and ASD diagnosis in childhood, but further follow-up studies are needed.

4.3 INFANT MEASURES AS PREDICTORS OF LATER CHILDHOOD INTELLECTUAL FUNCTIONING AT 36 MONTHS

These same attentional composites (proportion of looking, attention to figure versus background, active scanning, and attention to static versus dynamic stimuli) were also considered as predictors (using both *a priori* and *data-driven* approaches) for later intellectual functioning in childhood. Later intellectual functioning was measured by 36-month Mullen DQ. Subsequent analyses also considered 11- and 16-month Mullen DQ as predictors of later Mullen DQ in combination with significant predictors of risk and/or attentional composites. Collectively, these analyses illustrated three key findings. First, an attentional composite did not seem to emerge as a significant predictor of 36-month Mullen DQ until 16 months of age. Second, only attention to figure versus background (calculated using the *a priori* approach or limited to static tasks only) had some empirical support as an attentional predictor of later 36-month Mullen DQ. Third, when 16-month Mullen DQ was added as a predictor of 36-month Mullen DQ with risk and attention to figure versus background (calculated using either approach), the attentional composite became statistically nonsignificant, which may indicate that risk and 16-month Mullen DQ better predicted later intellectual functioning. However, given the small infant sample, interpretations of this exploratory study are made with caution. Additional research would be beneficial to further investigate these tentative interpretations.

The long-term predictive utility of the attention to figure versus background composite (at 16 months) for later intellectual functioning at 36 months would be consistent with previous findings showing relationships between infant attentional measures and later intellectual functioning in various at-risk populations, including infants at risk for later intellectual disability (Fagan et al., 1986). Therefore, this provides preliminary but tentative support that this well-established phenomenon may generalize to infants at heightened genetic risk for ASD. It also may suggest that infants' general attentional abilities, particularly in attending to the relevant figures, whether they are objects, faces or people of interest, could be a fruitful direction for more broadly measuring early developmental functioning. However, the extant literature suggests that infant visual attention composites to be a stronger predictor of later childhood intellectual functioning than standardized infant developmental assessments (for meta-analysis, see McCall & Carriger, 1993). Results from the present study diverge from this previous work and instead may tentatively suggest that infant Mullen DQs were better predictors (with risk) than visual attention composites of 36-month Mullen DQ. The emphasis on the FTII (Fagan & Detterman, 1992), which was developed as an early screening device for infants, in previous literature suggests that their task administration, which consisted of various visual comparisons presented within a single task, may be preferable to the present study's aggregation of task performance across diverse individual eye-tracking tasks. Improvements in the number and magnitude of visual attention composites' predictive utility for later Mullen DQ may be gained utilizing a similar testing format. Nonetheless, the present study may suggest an association between early intellectual functioning and later functioning as measured by the Mullen. Since the Mullen was administered across development from infancy to childhood, it was expected that an association would have emerged between infant Mullen DQs at 11 and 16 months with 36-month DQ.

4.4 CLINICAL IMPLICATIONS

Two key conclusions of the present study's findings form the foundation for its clinical implications. First, the present study provides some preliminary but tentative support that is consistent with extant literature that the creation of visual attention composites may be useful for identifying clinical populations (e.g., Corbett & Drewett, 2004; Drotar & Sturm, 1988; Elmer et al., 1969; Fagan & Singer, 1983; Fagan et al., 1986; Jacobson et al., 1996; Roberts et al., 2012; Rose, 1980; Rose, 1983; Rose & Feldman, 2000; Rose et al., 1978; Rose et al., 1979; Ruff, 1986; Ruff et al., 1986; Singer & Fagan, 1984; Singer et al., 1999; Struthers & Hansen, 1992). Second, the present study is the first known to date that may suggest the application of visual attention composites for identifying ASD in childhood (Frazier et al., 2016) to infant-sibling populations. With the known clinical applications of visual attention to diverse at-risk populations, potential clinical implications of the present study may be tentatively explored.

Although limited in sample size, the present study may suggest that further research could help develop a novel visual attention clinical battery to aid with early ASD diagnostics. One benefit of possibly developing an eye-tracking clinical tool is to provide a task with a concise time duration, which improves testing efficiency. Such a clinical tool would be of shorter duration (potentially 10-15 minutes total) than administration of an infant intellectual functioning measure, such as the Mullen, which requires a multitude of subscales and the achievement of basal and ceiling levels. Furthermore, an eye-tracking assessment tool may place significantly lower task demands on infant participants than the Mullen, which requires verbal and/or behavioral responses to an extensive number of prompts. Together, future benefits of an eye-tracking assessment tool could help reduce missing data that occurs during standardized intellectual functioning measures due to inability of infant participants to complete all subscales. This could be particularly advantageous if infants display fussiness or overactivity during intellectual functioning assessments. Further research would be needed to explore to what extent the addition of an eye-tracking clinical tool to a traditional clinical assessment of parent measures (e.g., interview, questionnaires) and infant measures may provide an efficient means of gaining supplemental information of infant development.

More specifically, a tentative interpretation of the results may suggest how an inclusion of various stimuli (e.g., faces, objects and people) and stimulus types (e.g., static and dynamic) that can be used to quantify diverse attentional processes (e.g., proportion of looking, attention to figures versus background) warrants further study for identifying infants to be later diagnosed with ASD. Diagnostic accuracy for the small sample size of ASD infants in the present study was not adequate for clinical use or for determining clinical utility of such an eye-tracking measure, so substantial follow-up testing and alterations would be required prior to considering a visual attention tool in the future. In combination with non-attentional infant measures, a visual attention clinical tool may be useful in the future for parsing other non-typical developmental pathways, such as language delays, from ASD. For infants with language delays, an eye-tracking assessment may provide further developmental information regarding the extent to which general information processing (in the form of attentional profiles) may be more indicative of typical or ASD development. In these cases with or without language delays, atypical performance on the eye-tracking clinical assessment may warrant infants to receive close developmental monitoring across later infancy and toddlerhood.

4.5 LIMITATIONS

Although this exploratory study provides some preliminary but tentative findings for the creation of visual attention composites in infant-sibling populations, a few limitations should be noted regarding the eye-tracking tasks used and sample characteristics. First, the eye-tracking tasks included in the present study were designed as separate tasks rather than an efficient attentional battery. As individual tasks, the time to complete all 12 possible tasks was sufficiently longer than would be ideal for infant populations, particularly those with difficult temperaments who may display fussiness during testing. Consequently, infant participants often did not complete all possible tasks. The majority of visual attention composites were not hindered by missing data, but three of the four visual attention composites that required completion of specific subsets of tasks (i.e., attention to novelty, attention to social versus nonsocial stimuli and maintenance of attention) were more stringent in nature, and thus, yielded lower rates of valid participant data for calculating a composite score. Although analyses exploring group differences based on risk across infancy could be conducted for these attentional composites of interest, additional analyses on the predictive utility of these three composites were not feasible in the present study but would be beneficial to assess in future work.

Second, in regard to sample characteristics, the sample sizes of ASD and NT infants (10 and 7, respectively) were limited, so results should be interpreted with caution. Overall, the ASD sample was fairly low functioning in their DQ scores, so it is difficult to parse out the extent to which visual attention composite differences or predictive values may be specific to identifying ASD relative to overall low intellectual functioning. Nonetheless, the present study was exploratory in nature, so these results may have actually underestimated attentional differences and the predictive role of visual attention composites for later ASD diagnosis, atypical development and general intellectual functioning.

4.6 FUTURE DIRECTIONS

Given the limitations of the present study, suggestions regarding future directions for methodology and samples in investigating visual attention composites are discussed. First, the exploration of visual attention composites in the present study provides some tentative, empirical evidence for future development and study of a visual attention clinical tool to assist in identifying atypical development and ASD diagnosis across infancy. While similar to the creation of the FTII (Fagan & Detterman, 1992), a potential visual attention clinical tool could be tailored to the identification of later ASD diagnosis. By creating and testing a singular, concise eye-tracking task, the overall time duration of the task may be shortened and more efficient to administer. Improving testing efficiency may help maximize infant participation completion.

Furthermore, although tentative models were difficult to interpret, the variety of visual attention composites that may show risk group differences and/or predictive utility for later childhood outcomes found in the present study may suggest that future research would also benefit from the inclusion of a multitude of stimuli incorporated into an eye-tracking battery to capture diverse attentional processes. This may have some benefit for future development of an eye-tracking clinical tool and would be a departure from the FTII (Fagan & Detterman, 1992), which focuses on the single attentional process of attention to novelty.

Future research should also continue to study visual attention composites across infancy in larger samples of infant-sibling populations. Increasing the statistical power of analyses may help elucidate the extent to which visual attention composites can be used to uniquely identify the developmental pathways of visual attention characteristic of ASD from non-typical outcomes, like children with language delays. Similarly, future research may benefit from larger samples of infants later diagnosed with ASD to explore developmental similarities and differences in the general attentional profiles *within* ASD, particularly between high-functioning and low-functioning individuals.

4.7 CONCLUSIONS

Collectively, results suggest several tentative conclusions. Regarding developmental trajectories in visual attention, findings may suggest that HR infants do not demonstrate increased attentional abilities from 11 to 16 months as LR infants do in overall active scanning and their attention to figures relative to the background during static tasks. As a set, attentional composites may be predictive of later childhood outcome classifications, but larger follow-up studies are needed to assess their clinical utility for identifying atypically developing populations and infants later diagnosed with ASD. Of the visual attention composites, the attention to figure versus background composite may also be predictive of later childhood intellectual functioning. Thus, as the first study to date to explore the creation of visual attention composites as early predictors of later childhood development and ASD diagnoses in infants at heightened genetic risk for ASD, these preliminary results must be interpreted with caution but provide some support for potential follow-up studies investigating a visual attention battery to assist with early ASD diagnostics.

5.0 TABLES

Table 1. Participant Characteristics across Infancy based on Genetic Risk Status.

	HR (*n* = 47)	**LR** (*n* = 39)
Gender (#)		
Male	30	20
Female	17	19
Race (#)		
Caucasian	45	37
African-American	1	2
More than one race	1	0
Ethnicity (#)		
Hispanic	5	1
Non-Hispanic	42	38
Mullen DQ at 11 months		
M (SD)	97.6 (15.7)*	104.6 (11.7)*
Range	69-133	74-133
Mullen DQ at 16 months		
M (SD)	95.1 (15.5)*	102.1 (13.9)*
Range	70-127	77-148
Diagnostic Classification		
ASD	10	0
Global developmental delay	1	0
Language delay	0	1
Social concerns	3	2
Typically developing	32	36
Classification Age Point		
24 months	2	1
36 months	18	13
48 months	26	25
CDI Words Produced at 24 months		
M (SD)	273.05 (167.54)	314.00 (157.68)

Range	5-572	18-630

Note. HR = high-risk; LR = low-risk; DQ = developmental quotient; 11-month Mullen DQ missing cases = 5 HR and 2 LR; 16-month Mullen DQ missing cases = 5 HR and 4 LR; Diagnostic classification missing cases = 1 HR; CDI = Communicative Development Inventory; CDI missing cases = 7 HR and 8 LR; *denotes independent samples *t*-test with $p < 0.05$

Table 2. Diagnostic Classification Criteria for Infant Participants at 24, 36 and/or 48 Months of Age.

	Criteria 1: Testing Results	**Criteria 2: Clinical Review**	**Criteria 3: Supplemental Information**
ASD	Meets at least spectrum cutoffs of all three diagnostic totals: Communication Total, Social Interaction Total, and Communication + Social Interaction Total	Clinical psychologist's review is required to warrant this outcome classification	
Global Developmental Delay (GDD)	Visual Reception and Receptive Language Mullen scores fall at least 1.5 SD below the normative Mean. Other domains of the Mullen may or may not also fall 1.5 SD below the mean	Clinical psychologist may exclude any child based on clinical opinion, but inclusion is dependent on concerning Mullen scores. (Clinical opinion may place infants in this outcome group even if scores do not quite meet the 1.5 SD cutoff.)	
Language Delay (LD)	One of the following is required: (1) Mullen scores fall at least 1.5 SD below the normative mean For Expressive and/or Receptive Language ONLY; (2) If CDI Words Produced falls at or below the 10th percentile, it may warrant this outcome but Clinical Review required	Clinical psychologist may include or exclude any child based on clinical opinion, although issues regarding articulation will not be included	This outcome may be a delay in: Expressive Language, Receptive Language or Both Expressive and Receptive Language
Social Concerns	One or both of the following:	Clinical psychologist may place	Reasons that Criteria 1 may be

(SC)	(1) Meets at least spectrum cutoffs on the ADOS Social Interaction Total ONLY (4 points or more); (2) ADOS Communication + Social Interaction Total within 2 points (or less) of spectrum cutoffs	a child meeting spectrum cutoffs here, in the case that a diagnosis of ASD is not appropriate. In addition, all children in this outcome must be reviewed to determine the cause for social concerns (i.e., Criteria 3) or if exclusion is necessary	displayed: Shyness and/or anxiety, behavioral issues, due to language delay, ASD-like, or Other (to be specified)
Typically Developing (TD)	Child must not meet any of the criteria listed above (however, they may have deficits in Gross Motor, Fine Motor, and/or Visual Reception Mullen scores	Any child with invalid testing results may be included here by the clinical psychologist	

Table 3. Participant characteristics by outcome classification.

	ASD (*n* = 10)	**NT** (*n* = 7)	**TD** (*n* = 68)
Gender (#)			
Male	6	3	40
Female	4	4	28
Race (#)			
Caucasian	8	6	67
African-American	1	1	1
More than one race	1	0	0
Ethnicity (#)			
Hispanic	1	0	5
Non-Hispanic	9	7	63
Autism Genetic Risk (#)			
HR	10	4	32
LR	0	3	36
Mullen DQ at 11 months			
M (SD)	91.89 (12.97)	98.86 (16.61)	102.44 (14.05)
Range	75-110	69-125	74-133
Mullen DQ at 16 months			
M (SD)	80.22 (8.94)	94.00 (13.24)	101.46 (14.23)
Range	70-98	82-117	75-148
Mullen DQ at 36 months			
M (SD)	78.25 (24.94)	96.75 (20.76)	115.02 (15.06)
Range	49-117	77-118	78-155
Classification Age Point			
24 months	1	0	2
36 months	5	1	25
48 months	4	6	41
ADOS Severity Index			
M (SD)	6.44 (1.51)	3.33 (1.21)	1.47 (0.82)
Range	5-10	1-4	1-4

CDI Words Produced at 24 months			
M (SD)	168.57 (172.63)	232.86 (169.72)	313.09 (155.95)
Range	5-425	41-458	18-630

Note. ASD = autism spectrum disorder; NT = non-typically developing; TD = typically developing; HR = high-risk; LR = low-risk; DQ = developmental quotient; 11-month Mullen DQ missing cases = 1 ASD and 6 TD; 16-month Mullen DQ missing cases = 1 ASD, 1 NT and 7 TD; 36-month Mullen DQ missing cases = 2 ASD, 3 NT and 9 TD; CDI = Communicative Development Inventory; CDI missing cases = 3 ASD and 11 TD.

Table 4. Operational Definitions for Calculating *A Priori* Visual Attention Composite Scores

Visual Attention Composite	Operational Definition Used in Calculation
Proportion of looking	The numerator consisted of the total duration of looking (in seconds) summed across all tasks viewed (with the maximum consisting of 12 tasks): Attractiveness Faces (AF), Emotion Faces (EM), Face Prototypes (FP), Dot Prototypes (DP), Face Memory (FM), Object Memory (OM) and six dynamic videos from *Mister Rogers' Neighborhood* television show (MR1, MR2, MR3, MR4, MR5, MR6). For each task, the total duration of looking was derived from the area of interest (AOI) capturing the total screen area. The denominator of this composite score was derived by summing the time duration of all tasks viewed (with the maximum consisting of all 12 tasks). Therefore, the denominator reflected the total possible looking duration of infant participants and mathematically controlled for variability in the number of tasks infant participants completed.
Active scanning	This composite reflected the number of fixations per second. The numerator consisted of the total number of fixations summed across all tasks viewed (AF, EM, FP, DP, FM, OM, MR1, MR2, MR3, MR4, MR5 and/or MR6). All fixations within the AOI characterizing the total screen area were included. The denominator of this composite score was the total duration of looking (in seconds) across the tasks.
Attention to figures vs. background	This composite score described the ratio of looking duration to figures or relevant aspects of stimuli/scenes to total looking duration to the background/non-relevant areas. All 12 tasks were included for this calculation. The numerator for this variable was calculated by summing the looking duration to figures/relevant areas of each task. For AF, EM, FP and FM, figures consisted of faces. For DP, figures consisted of dot patterns. For OM, figures consisted of objects (i.e., chairs). For MR1-6, figures consisted of people (faces and/or bodies) and objects held, moved or used by people (e.g., wooden blocks, toys). The denominator for this variable was calculated by subtracting the total duration of looking to figures from the total duration of looking to the screen across tasks.

Attention to novelty	This composite score characterized the proportion of looking to novel images during paired comparison test trials of familiar and novel images presented during FM and OM. This composite was only calculated for infants who completed both FM and OM. The numerator consisted of the sum of looking durations to AOIs of novel faces/objects during FM and OM. The denominator was calculated by summing the look durations to novel <u>and</u> familiar stimulus AOIs during FM and OM.
Attention to static vs. dynamic stimuli	This composite score illustrated the ratio of proportion of looking during the presentation of static stimuli to the proportion of looking during the presentation of dynamic stimuli. The numerator (which refers to the proportion of looking during static stimuli) was calculated by summing looking durations to the screen across static tasks (AF, EM, FP, DP, FM and/or OM) and then dividing by the total possible look duration of the tasks (i.e., the total length of time of stimuli presentation). The denominator characterized the proportion of looking during dynamic stimuli presentation. Similarly, this proportion was calculated by summing look durations to the screen across dynamic tasks (MR1, MR2, MR3, MR4, MR5 and/or MR6) and dividing by the total possible look duration of these tasks. Proportions were used for the numerator and denominator to control for variability across infants in the number and length of time infant participants viewed static and dynamic stimuli.
Attention to social vs. nonsocial stimuli	This composite score was a ratio of total looking duration during the presentation of static faces to total looking duration during the presentation of nonsocial stimuli (i.e., dot patterns and chairs). This composite score utilized the following subset of tasks: FP, FM, DP and OM. For infants who had completed all four tasks, the composite score was calculated with: • Numerator = sum of looking durations to face AOIs presented during FP and FM • Denominator = sum of looking durations to dot pattern/object AOIs during DP and OM For the remaining infants who had not completed all four tasks but had viewed one social and one nonsocial task pair (i.e., both FP + DP or FM + OM), the ratio was calculated with the numerator as the sum of looking durations to face AOIs presented during the social task (FP or FM) and the denominator as the sum of looking durations to nonsocial AOIs of the correspondingly paired task (DP or OM).

Maintenance of attention	This composite score reflected the average ratio of looking duration during the first half relative to the second half of dynamic stimuli presentations (MR1, MR2, MR3, MR4, MR5 and/or MR6). For each dynamic task, a ratio was calculated with the numerator as the total duration of looking during the first half of the video and the denominator as the total duration of looking to the second half of the video. Therefore, a maximum of six ratios (MR1-6) were calculated per infant. These ratios were averaged to yield one composite score.

Table 5. Extreme Outlier Frequencies of *A Priori* Attentional Composites Across 11 and 16 Months by Risk Group

	11 months		**16 months**	
	HR (*n* = 47)	LR (*n* = 39)	HR (*n* = 47)	LR (*n* = 39)
Proportion of looking				
Outliers removed (#)	0	0	0	1
Active scanning				
Outliers removed (#)	0	0	0	0
Attention to figure vs. background				
Outliers removed (#)	0	1	0	2
Attention to novelty				
Outliers removed (#)	0	0	0	1
Attention to static vs. dynamic				
Outliers removed (#)	1*	1	1	2
Attention to social vs. nonsocial				
Outliers removed (#)	3*	0	1	1
Maintenance of attention				
Outliers removed (#)	3	2	3	0

Note. HR = high-risk, LR = low-risk; * denotes that one infant within this HR group was later diagnosed with ASD

Table 6. Summary of Principal-Components Analyses of Eye-Tracking Tasks

	Component	Scale	Total tasks	Range of loadings
11-months				
	1	STAT	6	0.35-0.85
	2	DYN	6	0.56-0.83
16-months				
	1	STAT	6	0.55-0.82
	2	DYN	6	0.56-0.87

Note. DYN = Dynamic, STAT = Static

Table 7. Extreme Outlier Frequencies of *Data-Driven* Attentional Composites Across 11 and 16 Months by Risk Group

	11 months		**16 months**	
	HR (*n*=47)	LR (*n*=39)	HR (*n*=47)	LR (*n*=39)
Proportion of looking (static tasks only)				
Outliers removed (#)	0	0	0	0
Proportion of looking (dynamic tasks only)				
Outliers removed (#)	0	0	0	0
Active scanning (static tasks only)				
Outliers removed (#)	0	0	1	0
Active scanning (dynamic tasks only)				
Outliers removed (#)	1*	0	0	0
Attention to figure vs. background (static only)				
Outliers removed (#)	0	2	3*	1
Attention to figure vs. background (dynamic only)				
Outliers removed (#)	3*	3	2*	1

Note. HR = high-risk, LR = low-risk; * denotes that one infant within this HR group was later diagnosed with ASD

Table 8. Pearson Correlations for *A Priori* Visual Attention Composite Scores at 11 Months

	PL	AS	FIG	NOV	SVD	SOC	MA
Proportion of looking (PL)							
Pearson's correlation	1						
p-value	-						
Active scanning (AS)							
Pearson's correlation	-0.36*	1					
p-value	0.001	-					
Figure vs. background (FIG)							
Pearson's correlation	0.13	0.10	1				
p-value	0.24	0.36	-				
Attention to novelty (NOV)							
Pearson's correlation	-0.06	-0.15	0.00	1			
p-value	0.64	0.25	0.98	-			
Static vs. dynamic (SVD)							
Pearson's correlation	-0.09	0.43*	0.10	-0.06	1		
p-value	0.42	<0.001	0.38	0.68	-		
Social vs. nonsocial (SOC)							
Pearson's correlation	-0.12	0.13	0.38	-0.12	0.38	1	
p-value	0.43	0.40	0.01	0.46	0.01	-	
Maintenance of attention (MA)							
Pearson's correlation	-0.08	0.22	0.26	-0.17	0.17	0.03	1
p-value	0.54	0.09	0.05	0.24	0.20	0.88	-

Note. Bonferroni correction for 49 comparisons (7x7 intercorrelations matrix) yields adjusted alpha of ≤ 0.001; * denotes significance at $p \leq 0.001$

Table 9. Pearson Correlations for *A Priori* Visual Attention Composite Scores at 16 Months

	PL	**AS**	**FIG**	**NOV**	**SVD**	**SOC**	**MA**
Proportion of looking (PL)							
Pearson's correlation	1						
p-value	-						
Active scanning (AS)							
Pearson's correlation	-0.48*	1					
p-value	<0.001	-					
Figure vs. background (FIG)							
Pearson's correlation	0.27	0.00	1				
p-value	0.01	1.00	-				
Attention to novelty (NOV)							
Pearson's correlation	0.15	-0.06	0.17	1			
p-value	0.26	0.68	0.22	-			
Static vs. dynamic (SVD)							
Pearson's correlation	-0.29	0.06	0.17	-0.11	1		
p-value	0.01	0.62	0.14	0.43	-		
Social vs. nonsocial (SOC)							
Pearson's correlation	-0.16	-0.10	-0.29	-0.19	0.07	1	
p-value	0.34	0.54	0.07	0.24	0.69	-	
Maintenance of attention (MA)							
Pearson's correlation	-0.19	0.26	-0.19	-0.08	-0.06	0.30	1
p-value	0.15	0.04	0.15	0.56	0.66	0.08	-

Note. Bonferroni correction for 49 comparisons (7x7 intercorrelations matrix) yields adjusted alpha of ≤ 0.001; * denotes significance at $p \leq 0.001$

Table 10. Pearson Correlations for *Data-Driven* Visual Attention Composite Scores at 11 Months

	PL-S	PL-D	AS-S	AS-D	FIG-S	FIG-D
PL-S						
Pearson's correlation	1					
p-value	-					
PL-D						
Pearson's correlation	0.32	1				
p-value	0.003	-				
AS-S						
Pearson's correlation	-0.32	-0.09	1			
p-value	0.002	0.40	-			
AS-D						
Pearson's correlation	-0.09	-0.69	0.15	1		
p-value	0.42	<0.001*	0.18	-		
FIG-S						
Pearson's correlation	0.32	0.03	-0.06	0.08	1	
p-value	0.003	0.77	0.62	0.46	-	
FIG-D						
Pearson's correlation	0.09	0.21	0.07	-0.12	-0.05	1
p-value	0.46	0.06	0.57	0.30	0.66	-
Proportion of looking (PL)						
Pearson's correlation	0.87	0.72	-0.20	-0.39	0.27	0.21
p-value	<0.001*	<0.001*	0.07	<0.001*	0.02	0.07
Active scanning (AS)						
Pearson's correlation	-0.17	-0.52	0.66	0.70	0.01	-0.03
p-value	0.12	<0.001*	<0.001*	<0.001*	0.90	0.82
Figure vs. background (FIG)						
Pearson's correlation	0.16	-0.04	0.07	0.13	0.49	0.45
p-value	0.15	0.71	0.52	0.23	<0.001*	<0.001*
Attention to novelty (NOV)						
Pearson's correlation	-0.05	-0.06	-0.17	-0.14	0.02	0.17
p-value	0.72	0.66	0.21	0.31	0.90	0.21

Static vs. dynamic (SVD)						
Pearson’s correlation	0.31	-0.66	-0.03	0.59	0.24	-0.16
p-value	0.004	<0.001*	0.78	<0.001*	0.04	0.17
Social vs. nonsocial (SOC)						
Pearson’s correlation	-0.03	-0.19	0.07	0.16	0.00	-0.26
p-value	0.85	0.21	0.63	0.30	0.98	0.10
Maintenance of attention (MA)						
Pearson’s correlation	0.05	-0.28	-0.02	0.43	0.19	0.11
p-value	0.70	0.03	0.86	0.001	0.15	0.41

Note. AS-D = active scanning (dynamic tasks only); AS-S = active scanning (static tasks only); FIG-D = attention to figure vs. background (dynamic tasks only); FIG-S = attention to figure vs. background (static tasks only); PL-D = proportion of looking (dynamic tasks only); PL-S = proportion of looking (static tasks only); Bonferroni correction for 78 comparisons (6x13 correlations) yields adjusted alpha of ≤ 0.0006; * denotes significance at $p \leq 0.0006$

Table 11. Pearson Correlations for *Data-Driven* Visual Attention Composite Scores at 16 Months

	PL-S	PL-D	AS-S	AS-D	FIG-S	FIG-D
PL-S						
Pearson's correlation	1					
p-value	-					
PL-D						
Pearson's correlation	0.32	1				
p-value	0.003	-				
AS-S						
Pearson's correlation	-0.32	-0.09	1			
p-value	0.002	0.40	-			
AS-D						
Pearson's correlation	-0.09	-0.69	0.15	1		
p-value	0.42	<0.001*	0.18	-		
FIG-S						
Pearson's correlation	0.32	0.03	-0.06	0.08	1	
p-value	0.003	0.77	0.62	0.46	-	
FIG-D						
Pearson's correlation	0.09	0.21	0.07	-0.12	-0.05	1
p-value	0.46	0.06	0.57	0.30	0.66	-
Proportion of looking (PL)						
Pearson's correlation	0.87	0.72	-0.20	-0.39	0.27	0.21
p-value	<0.001*	<0.001*	0.07	<0.001*	0.02	0.07
Active scanning (AS)						
Pearson's correlation	-0.17	-0.52	0.66	0.70	0.01	-0.03
p-value	0.12	<0.001*	<0.001*	<0.001*	0.90	0.82
Figure vs. background (FIG)						
Pearson's correlation	0.16	-0.04	0.07	0.13	0.49	0.45
p-value	0.15	0.71	0.52	0.23	<0.001*	<0.001*
Attention to novelty (NOV)						
Pearson's correlation	-0.05	-0.06	-0.17	-0.14	0.02	0.17
p-value	0.72	0.66	0.21	0.31	0.90	0.21

Static vs. dynamic (SVD)						
Pearson's correlation	0.31	-0.66	-0.03	0.59	0.24	-0.16
p-value	0.004	<0.001*	0.78	<0.001*	0.04	0.17
Social vs. nonsocial (SOC)						
Pearson's correlation	-0.03	-0.19	0.07	0.16	0.00	-0.26
p-value	0.85	0.21	0.63	0.30	0.98	0.10
Maintenance of attention (MA)						
Pearson's correlation	0.05	-0.28	-0.02	0.43	0.19	0.11
p-value	0.70	0.03	0.86	0.001	0.15	0.41

Note. AS-D = active scanning (dynamic tasks only); AS-S = active scanning (static tasks only); FIG-D = attention to figure vs. background (dynamic tasks only); FIG-S = attention to figure vs. background (static tasks only); PL-D = proportion of looking (dynamic tasks only); PL-S = proportion of looking (static tasks only); Bonferroni correction for 78 comparisons (6x13 correlations) yields adjusted alpha of ≤ 0.0006; * denotes significance at $p \leq 0.0006$

Table 12. Descriptive Data for Visual Attention Composite Scores by Genetic Risk across Infancy

	11 months		16 months	
	HR (*n* = 47)	LR (*n* = 39)	HR (*n* = 47)	LR (*n* = 39)
Proportion of looking (PL)				
Mean (SD)	0.35 (0.12)	0.34 (0.13)	0.67 (0.15)	0.69 (0.12)
Range	0.11-0.70	0.13-0.73	0.34-1.00	0.34-1.00
PL (static tasks only)				
Mean (SD)	0.34 (0.13)	0.32 (0.13)	0.37 (0.16)	0.35 (0.14)
Range	0.06-0.65	0.04-0.70	0.16-0.79	0.08-0.70
PL (dynamic tasks only)				
Mean (SD)	0.39 (0.19)	0.41 (0.18)	0.43 (0.18)	0.42 (0.18)
Range	0.02-0.82	0.11-0.76	0.03-0.80	0.03-0.83
Active scanning (AS)				
Mean (SD)	2.84 (0.61)	2.79 (0.51)	2.82 (0.61)	2.97 (0.58)
Range	1.76-4.88	2.08-4.08	1.93-4.73	1.93-4.37
AS (static tasks only)				
Mean (SD)	3.26 (0.86)	3.06 (0.56)	3.14 (0.75)	3.26 (0.55)
Range	1.80-6.23	2.19-4.53	1.96-5.89	2.21-4.37
AS (dynamic tasks only)				
Mean (SD)	2.40 (0.65)	2.51 (0.71)	2.34 (0.66)	2.55 (0.78)
Range	1.13-4.19	1.37-4.13	1.46-4.68	1.55-4.40
Attention to figure vs. background (FIG)				
Mean (SD)	4.85 (2.67)	4.75 (1.93)	4.90 (1.98)	5.27 (1.98)
Range	2.04-15.03	1.72-9.32	1.80-10.80	1.38-11.14
FIG (static tasks only)				
Mean (SD)	6.68 (3.21)	6.01 (3.12)	7.06 (3.64)	8.35 (4.36)
Range	1.88-17.74	1.52-12.97	0.80-17.19	1.81-21.72
FIG (dynamic tasks only)				
Mean (SD)	2.92 (2.30)	3.33 (2.13)	3.26 (1.71)	3.30 (1.78)

Range	0.57-11.68	0.47-11.48	0.04-7.67	0.90-9.14
Attention to novelty				
Mean (SD)	0.51 (0.09)	0.50 (0.10)	0.52 (0.09)	0.55 (0.07)
Range	0.35-0.78	0.28-0.71	0.32-0.71	0.40-0.71
Attention to static vs. dynamic				
Mean (SD)	1.03 (0.57)	0.85 (0.38)	0.93 (0.43)	0.86 (0.32)
Range	0.24-2.74	0.16-1.84	0.31-2.25	0.40-1.63
Attention to social vs. nonsocial				
Mean (SD)	1.70 (1.06)	1.53 (0.75)	1.70 (1.06)	1.31 (0.83)
Range	0.55-5.20	0.23-2.77	0.55-5.20	0.43-3.68
Maintenance of attention				
Mean (SD)	2.64 (2.12)	2.26 (1.24)	3.26 (3.96)	2.46 (1.74)
Range	0.00-8.58	0.00-4.83	0.13-18.19	0.15-7.18

Note. HR = high-risk, LR = low-risk

Table 13. Results of 2x2 (Age x Risk Status) Repeated Measures Analysis of Variance

	Age (11m & 16m)	**Risk Status**	**Age x Risk Status**
Proportion of looking (PL)	$F(1,83) = 446.06$ $p < 0.001$***	$F(1,83) = 0.14$ $p = 0.71$	$F(1,83) = 0.58$ $p = 0.45$
PL (static tasks only)	$F(1,84) = 4.44$ $p < 0.05$**	$F(1,84) = 0.60$ $p = 0.44$	$F(1,84) = 0.001$ $p = 0.97$
PL (dynamic tasks only)	$F(1,80) = 1.96$ $p = 0.17$	$F(1,80) = 0.12$ $p = 0.73$	$F(1,80) = 0.29$ $p = 0.59$
Active scanning (AS)	$F(1,84) = 1.61$ $p = 0.21$	$F(1,84) = 0.22$ $p = 0.64$	$F(1,84) = 1.61$ $p < 0.10$*
AS (static tasks only)	$F(1,83) = 0.91$ $p = 0.34$	$F(1,83) = 0.01$ $p = 0.94$	$F(1,83) = 2.86$ $p = 0.11$
AS (dynamic tasks only)	$F(1,79) = 0.11$ $p = 0.75$	$F(1,79) = 1.33$ $p = 0.25$	$F(1,79) = 0.18$ $p = 0.68$
Attention to figure vs. background (FIG)	$F(1,81) = 0.66$ $p = 0.42$	$F(1,81) = 0.06$ $p = 0.81$	$F(1,81) = 0.41$ $p = 0.52$
FIG (static tasks only)	$F(1,77) = 8.08$ $p < 0.01$**	$F(1,77) = 0.43$ $p = 0.52$	$F(1,77) = 3.43$ $p < 0.10$*
FIG (dynamic tasks only)	$F(1,71) = 0.03$ $p = 0.87$	$F(1,71) = 0.04$ $p = 0.83$	$F(1,71) = 0.94$ $p = 0.34$
Attention to novelty	$F(1,49) = 2.61$ $p = 0.11$	$F(1,49) = 0.09$ $p = 0.77$	$F(1,49) = 1.16$ $p = 0.29$

Attention to static vs. dynamic	$F(1,76) = 0.09$ $p = 0.76$	$F(1,76) = 2.45$ $p = 0.12$	$F(1,76) = 0.72$ $p = 0.40$
Attention to social vs. nonsocial	$F(1,27) = 2.36$ $p = 0.14$	$F(1,27) = 0.79$ $p = 0.38$	$F(1,27) = 0.10$ $p = 0.76$
Maintenance of attention	$F(1,56) = 2.82$ $p < 0.10$*	$F(1,56) = 0.60$ $p = 0.44$	$F(1,56) = 1.20$ $p = 0.28$

Note. m = months; *** indicates significance at $p < 0.001$; ** indicates significance at $p \leq 0.05$; * indicates trend at $p \leq 0.10$

Table 14. Descriptive Data for Visual Attention Composite Scores at 11 Months by Outcome Group

	ASD (*n* = 10)	**NT** (*n* = 7)	**TD** (*n* = 68)
Proportion of looking			
Mean (SD)	0.32 (0.15)	0.30 (0.09)	0.36 (0.12)
Range	0.17-0.70	0.15-0.40	0.11-0.73
Proportion of looking (static tasks only)			
Mean (SD)	0.31 (0.13)	0.31 (0.09)	0.33 (0.13)
Range	0.18-0.65	0.15-0.42	0.04-0.70
Proportion of looking (dynamic tasks only)			
Mean (SD)	0.32 (0.21)	0.27 (0.09)	0.43 (0.18)
Range	0.02-0.76	0.14-0.43	0.09-0.82
Active scanning			
Mean (SD)	3.05 (0.84)	3.11 (0.57)	2.77 (0.50)
Range	2.21-4.88	2.41-4.08	1.76-3.85
Active scanning (static tasks)			
Mean (SD)	3.55 (1.12)	3.28 (0.60)	3.12 (0.67)
Range	2.39-6.20	2.53-4.22	1.80-6.23
Active scanning (dynamic tasks)			
Mean (SD)	2.55 (0.57)	2.85 (0.74)	2.40 (0.68)
Range	1.75-3.32	2.05-4.19	1.13-4.13
Attention to figure vs. background			
Mean (SD)	4.38 (2.59)	4.30 (1.89)	4.94 (2.40)
Range	2.04-10.80	2.09-6.81	1.72-15.03
Attention to figure vs. background (static tasks)			
Mean (SD)	5.64 (3.38)	5.84 (3.04)	6.55 (3.20)
Range	2.46-11.47	1.52-9.95	1.79-17.74
Attention to figure vs. background (dynamic tasks)			
Mean (SD)	2.46 (1.71)	4.38 (3.74)	3.10 (2.11)
Range	0.57-5.53	1.11-11.48	0.47-11.68
Attention to novelty			
Mean (SD)	0.47 (0.07)	0.61 (0.13)	0.50 (0.09)
Range	0.40-0.55	0.47-0.78	0.28-0.70

Attention to static vs. dynamic			
Mean (SD)	1.02 (0.48)	1.17 (0.24)	0.91 (0.52)
Range	0.45-1.85	0.78-1.54	0.16-2.74
Attention to social vs. nonsocial			
Mean (SD)	2.75 (1.85)	0.98 (0.35)	1.64 (0.89)
Range	1.44-4.06	0.60-1.29	0.23-5.20
Maintenance of attention			
Mean (SD)	2.59 (1.71)	2.65 (2.57)	2.44 (1.70)
Range	0.23-4.20	0.41-7.68	0.00-8.58

Note. ASD = autism spectrum disorder; NT = non-typically developing; TD = typically developing

Table 15. Descriptive Data for Visual Attention Composite Scores at 16 Months by Outcome Group

	ASD (*n* = 10)	NT (*n* = 7)	TD (*n* = 68)
Proportion of looking			
Mean (SD)	0.61 (0.18)	0.59 (0.15)	0.69 (0.12)
Range	0.34-0.87	0.34-0.83	0.41-1.00
Proportion of looking (static tasks only)			
Mean (SD)	0.37 (0.21)	0.25 (0.11)	0.37 (0.14)
Range	0.16-0.79	0.08-0.43	0.13-0.70
Proportion of looking (dynamic tasks only)			
Mean (SD)	0.40 (0.18)	0.34 (0.17)	0.44 (0.18)
Range	0.17-0.80	0.18-0.63	0.03-0.83
Active scanning			
Mean (SD)	2.87 (0.79)	3.01 (0.57)	2.89 (0.59)
Range	2.13-4.73	2.47-3.72	1.93-4.37
Active scanning (static tasks only)			
Mean (SD)	3.33 (1.16)	3.33 (0.52)	3.17 (0.58)
Range	1.96-5.89	2.72-3.88	2.06-4.54
Active scanning (dynamic tasks only)			
Mean (SD)	2.48 (0.45)	2.56 (0.60)	2.43 (0.77)
Range	1.59-3.09	1.75-3.33	1.46-4.68
Attention to figure vs. background			
Mean (SD)	4.38 (2.59)	4.77 (2.39)	5.31 (1.94)
Range	2.04-10.80	1.38-9.02	1.98-11.14
Attention to figure vs. background (static tasks)			
Mean (SD)	4.97 (2.52)	10.05 (5.98)	7.81 (3.81)
Range	0.80-9.09	1.81-19.63	2.04-21.72
Attention to figure vs. background (dynamic tasks)			
Mean (SD)	2.62 (1.25)	1.92 (0.88)	3.51 (1.79)
Range	0.04-4.18	0.71-3.18	0.90-9.14
Attention to novelty			
Mean (SD)	0.47 (0.09)	0.56 (0.09)	0.53 (0.07)
Range	0.37-0.58	0.45-0.71	0.32-0.71

Attention to static vs. dynamic			
Mean (SD)	0.95 (0.38)	0.81 (0.43)	0.89 (0.38)
Range	0.43-1.57	0.40-1.63	0.31-2.25
Attention to social vs. nonsocial			
Mean (SD)	0.98 (0.37)	1.53 (0.90)	1.34 (0.83)
Range	0.57-1.26	0.78-2.72	0.43-3.84
Maintenance of attention			
Mean (SD)	5.21 (4.34)	4.61 (6.17)	2.46 (2.18)
Range	2.93-11.71	0.59-18.19	0.13-11.32

Note. ASD = autism spectrum disorder; NT = non-typically developing; TD = typically developing

Table 16. *A Priori* and *Data-Driven* Predictors Considered for Binary Logistic Regression Analyses

A Priori Approach	
Predictors	**Description**
risk	Genetic risk status
proplook	Proportion of looking composite
actscan	Active scanning composite
figback	Attention to figure versus background composite
statdyn	Attention to static versus dynamic stimuli composite

Data-Driven Approach	
Predictors	**Description**
risk	Genetic risk status
lookstat	Proportion of looking during static tasks
lookdyn	Proportion of looking during dynamic tasks
figstat	Attention to figures versus background during static tasks
figdyn	Attention to figures versus background during dynamic tasks
activestat	Active scanning during static tasks
activedyn	Active scanning during dynamic tasks
statdyn	Attention to static versus dynamic stimuli

Table 17. Logistic Regression Results of Predicting Atypical Development or ASD Diagnosis from 11 Months

	Regression Predicting Atypical Development		
A Priori Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	1.69 (0.02)	5.42	1.36 – 21.66
proplook	-2.18 (0.46)	0.11	0.00 – 34.20
figback	-0.13 (0.32)	0.88	0.68 – 1.14
actscan	0.84 (0.12)	2.33	0.80 – 6.74
Sample Size	***n***		
Atypical Development Classification	17		
Typical Development Classification	67		
Data-Driven Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	2.97 (0.01)	19.55	2.24 – 170.47
lookstat	4.09 (0.47)	59.75	0.001 – 4093759.27
lookdyn	-12.05 (0.04)	0.00	0.00 – 0.48
figstat	-0.05 (0.66)	0.95	0.75 – 1.20
figdyn	0.15 (0.29)	1.17	0.88 – 1.55
activestat	0.21 (0.69)	1.23	0.44 – 3.43
activedyn	0.22 (0.76)	1.24	0.30 – 5.08
statdyn	-2.85 (0.10)	0.06	0.002 – 1.78
Sample Size	***n***		
Atypical Development Classification	14		
Typical Development Classification	59		

	Regression Predicting ASD Diagnosis		
A Priori Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	19.82 (0.99)	403718424	0.00 –

figback	-0.09 (0.59)	0.92	0.68 – 1.25
actscan	0.62 (0.31)	1.86	0.57 – 6.10
Sample Size	***n***		
ASD Classification	9		
Non-ASD (TD or NT) Classification	71		
Data-Driven Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	19.85 (0.99)	416759488	0.00 –
activestat	0.46 (0.27)	1.59	0.70 – 3.63
lookdyn	-3.29 (0.28)	0.04	0.00 – 14.97
statdyn	-0.69 (0.48)	0.50	0.07 – 3.41
Sample Size	***n***		
ASD Classification	8		
Non-ASD (TD or NT) Classification	71		

Note. *activedyn* = active scanning during dynamic tasks; *activestat* = active scanning during static tasks; *actscan* = active scanning; ASD = autism spectrum disorder; CI = confidence interval; *figback* = attention to figure versus background; *figdyn* = attention to figure versus background during dynamic tasks; *figstat* = attention to figure versus background during static tasks; *lookdyn* = proportion of looking during dynamic tasks; *lookstat* = proportion of looking during static tasks; NT = non-typically developing; OR = odds ratio; *proplook* = proportion of looking; *statdyn* = attention to static versus dynamic stimuli; TD = typically developing

Table 18. Logistic Regression Results of Predicting Atypical Development or ASD Diagnosis from 16 Months

	Regression Predicting Atypical Development		
A Priori Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	1.56 (0.03)	4.76	1.14 – 19.85
proplook	-5.38 (0.08)	0.01	0.00 – 1.73
figback	-0.15 (0.40)	0.86	0.61 – 1.22
actscan	-0.26 (0.68)	0.77	0.22 – 2.65
statdyn	-0.55 (0.49)	0.58	0.12 – 2.75
Sample Size	***n***		
Atypical Development Classification	17		
Typical Development Classification	62		
Data-Driven Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	1.97 (0.02)	7.20	1.41 – 36.80
lookstat	14.81 (0.09)	2702845.17	0.09 – 8.14E13
lookdyn	-23.72 (0.01)	0.00	0.00 – 0.002
figstat	0.19 (0.10)	1.20	0.97 – 1.50
activestat	-1.45 (0.09)	0.24	0.05 – 1.22
statdyn	-9.12 (0.03)	0.00	0.00 – 0.32
Sample Size	***n***		
Atypical Development Classification	15		
Typical Development Classification	58		
	Regression Predicting ASD Diagnosis		
A Priori Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	19.85 (0.99)	416220324	0.00 –
proplook	-1.80 (0.64)	0.17	0.00 – 333.15

figback	-0.45 (0.14)	0.64	0.36 – 1.15
actscan	-0.31 (0.70)	0.73	0.15 – 3.48
Sample Size	***n***		
ASD Classification	10		
Non-ASD (TD or NT) Classification	69		
Data-Driven Model			
Independent Variables	**log-odds (*p*)**	**OR**	**95% CI**
risk	23.07 (0.99)	1.04E10	0.00 –
lookstat	47.06 (0.07)	2.75E20	0.06 – 1.37E42
lookdyn	-36.97 (0.09)	0.00	0.00 – 277.35
figstat	-0.44 (0.12)	0.64	0.37 – 1.12
figdyn	-0.67 (0.33)	0.51	0.13 – 1.97
statdyn	-19.17 (0.09)	0.00	0.00 – 23.93
Sample Size	***n***		
ASD Classification	8		
Non-ASD (TD or NT) Classification	66		

Note. *activedyn* = active scanning during dynamic tasks; *activestat* = active scanning during static tasks; *actscan* = active scanning; ASD = autism spectrum disorder; CI = confidence interval; *figback* = attention to figure versus background; *figdyn* = attention to figure versus background during dynamic tasks; *figstat* = attention to figure versus background during static tasks; *lookdyn* = proportion of looking during dynamic tasks; *lookstat* = proportion of looking during static tasks; NT = non-typically developing; OR = odds ratio; *proplook* = proportion of looking; *statdyn* = attention to static versus dynamic stimuli; TD = typically developing

Table 19. Beta Weights for Multiple Linear Regression Results of Predicting 36-Month Mullen DQ from 11- and 16-Month Data

	β	*p*
11-Month Model with Risk Predictor		
risk	-0.50	< 0.001
11-Month Model with Risk and Infant Mullen DQ		
Predictors		
risk	-0.41	< 0.001
Mullen DQ at 11m	0.34	< 0.01
16-Month Model with Risk and A Priori Attentional Predictors		
Predictors		
risk	-0.48	< 0.001
figback	0.25	0.01
16-Month Model with Risk and Data-Driven Attentional Predictors		
Predictors		
risk	-0.47	< 0.001
figstat	0.20	0.06
16-Month Model with Risk and Infant Mullen DQ		
Predictors		
risk	-0.43	< 0.001
Mullen DQ at 16m	0.47	< 0.001

Note. *DQ = Developmental Quotient; figback* = attention to figure versus background *figstat* = attention to figure versus background during static tasks

6.0 FIGURES

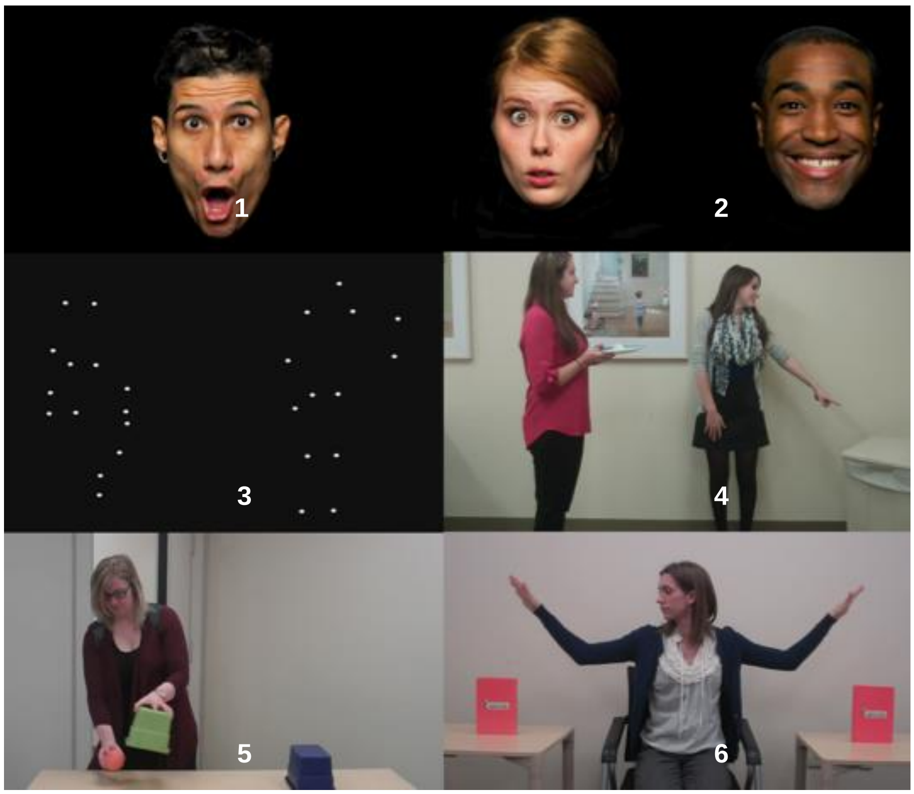

Figure 1. Six example stimuli used for visual attention composites of autism risk index (ARI). Individual emotive faces (1), paired emotive faces (2), biological vs. non-biological motion (3), joint attention bid (4), natural interaction (5) and predictive gaze (6).

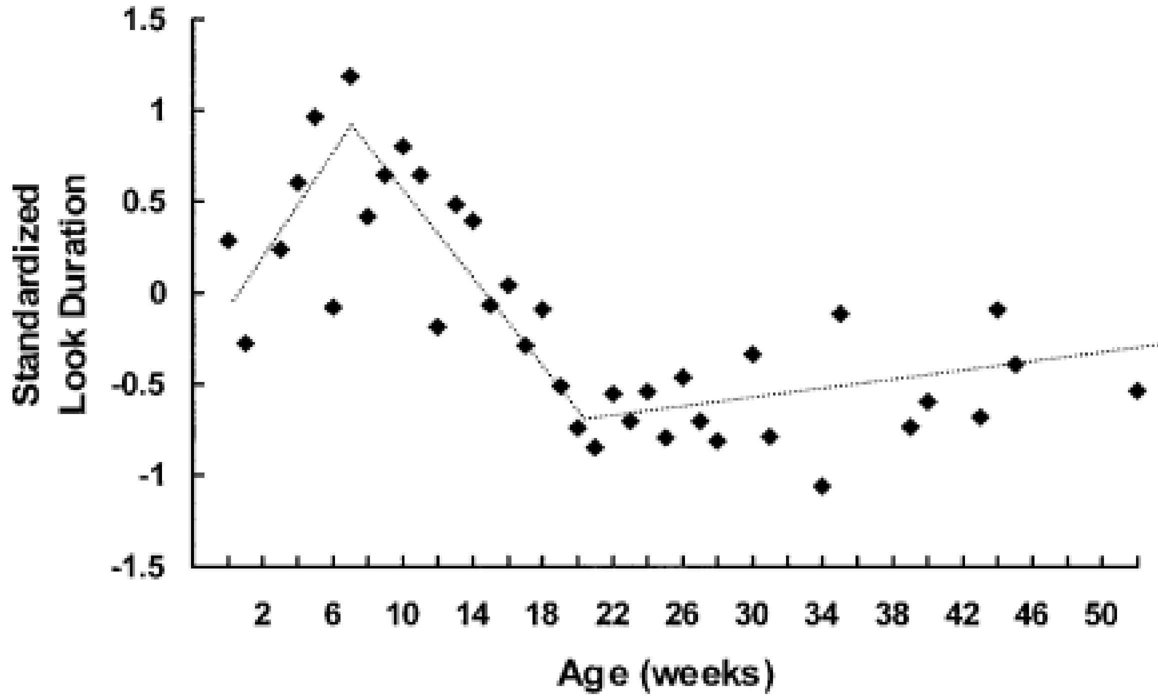

Figure 2. Developmental changes in infant look duration.

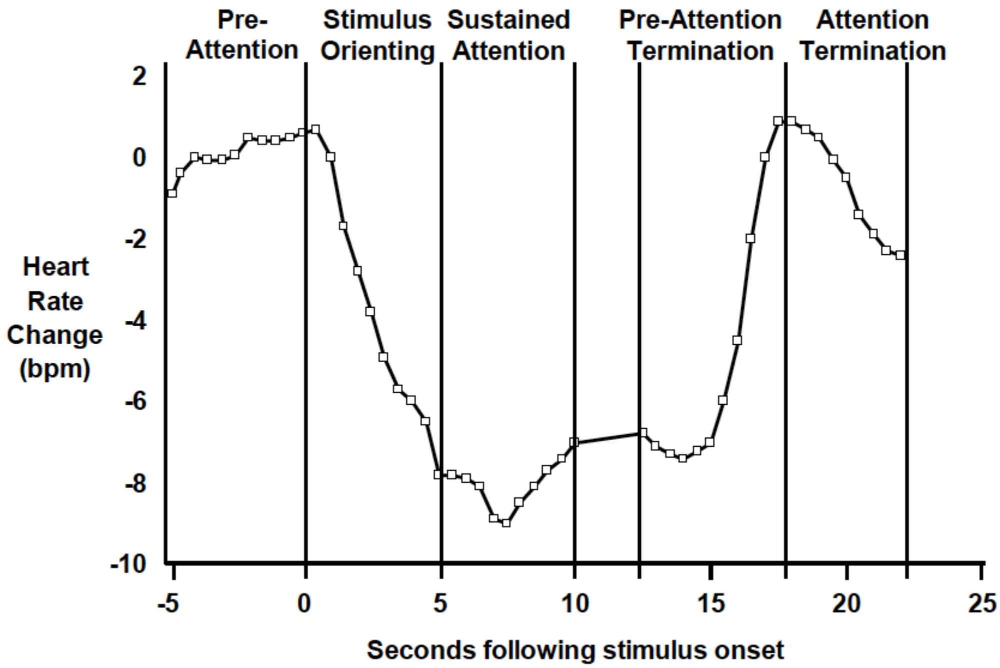

Figure 3. Model of attention phases measured by heart rate.

Figure 4. Example emotion face stimulus.

Figure 5. Example attractiveness face stimulus.

Figure 6. Example test trial from face prototype task.

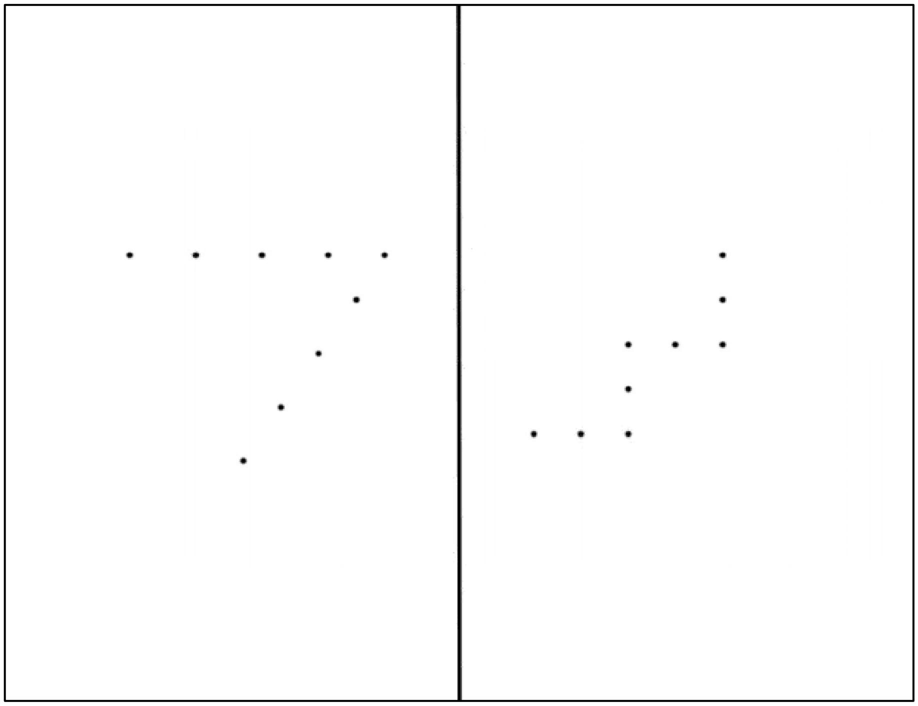

Figure 7. Example test trial from dot prototype task.

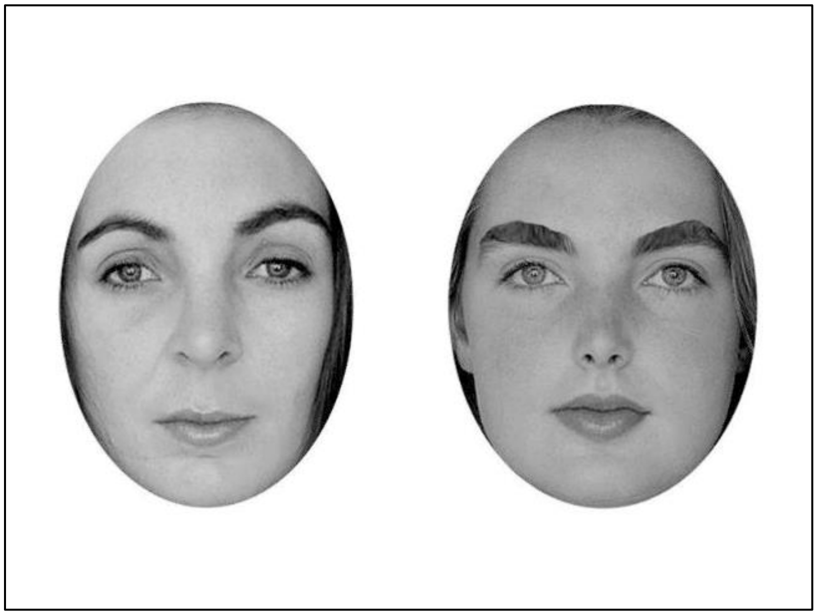

Figure 8. Example face memory stimulus.

Figure 9. Example object memory stimulus.

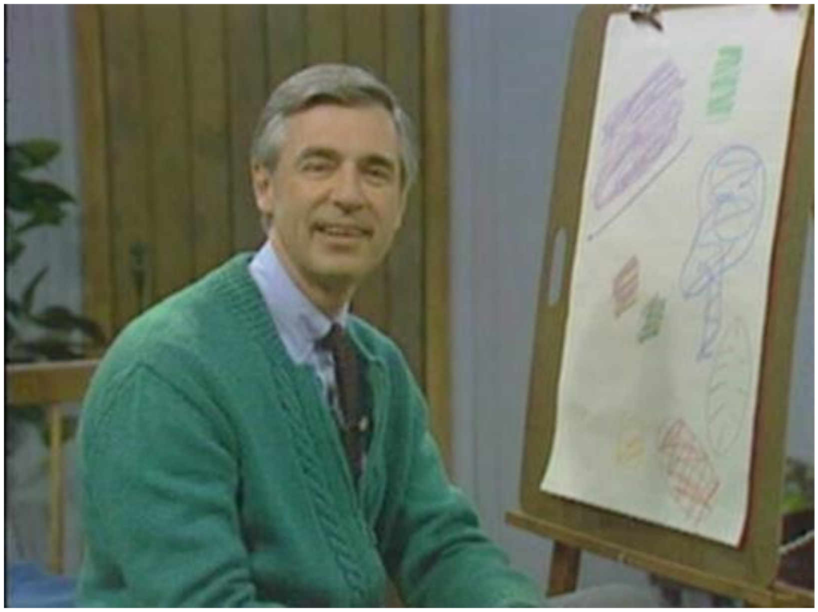

Figure 10. Still frame image from dynamic MR2 video.

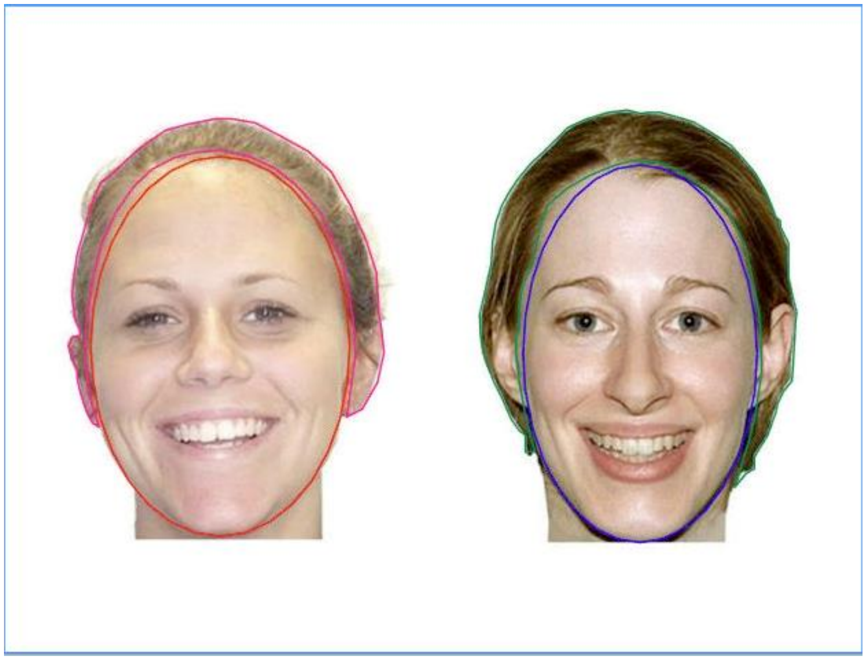

Figure 11. Example stimulus with designated regions of interest (ROI).

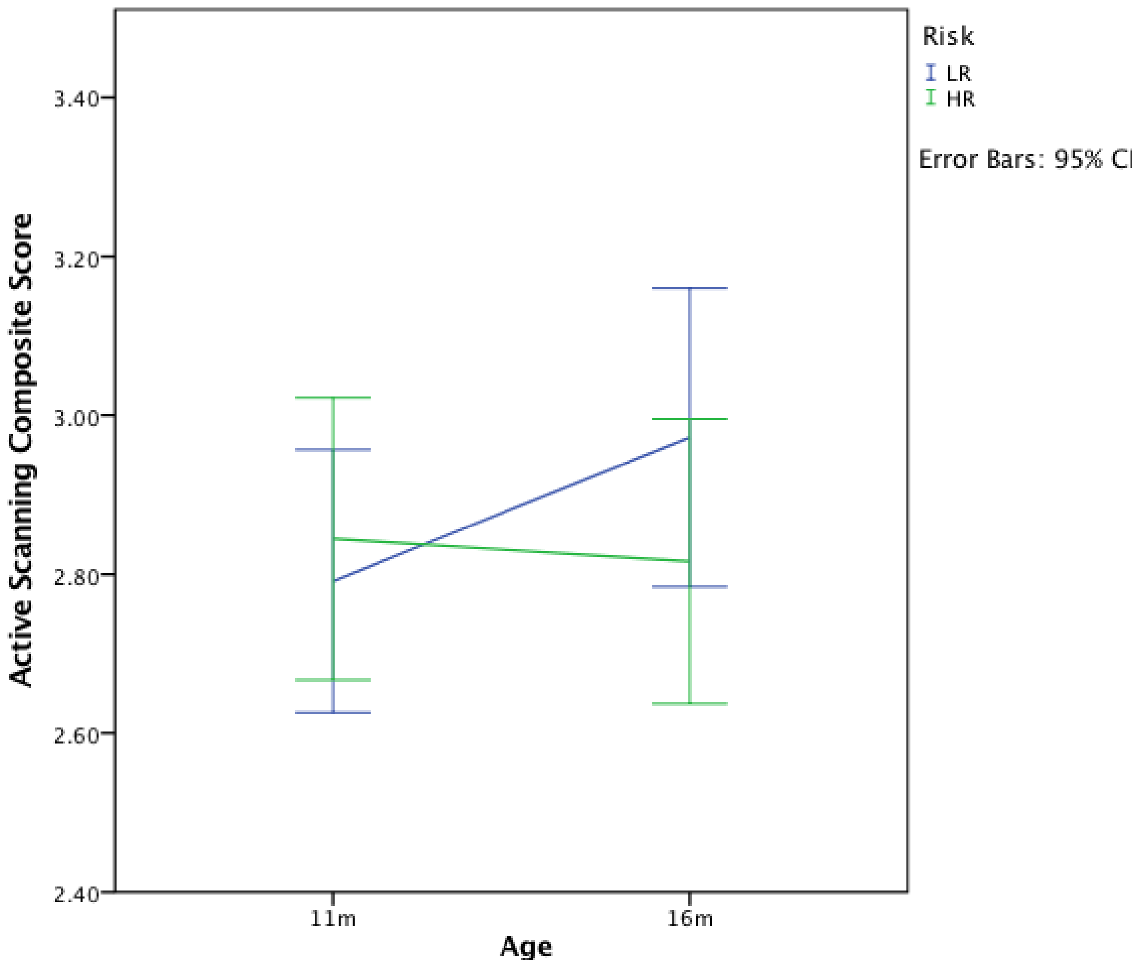

Figure 12. Risk status by age (in months) on active scanning composite score.

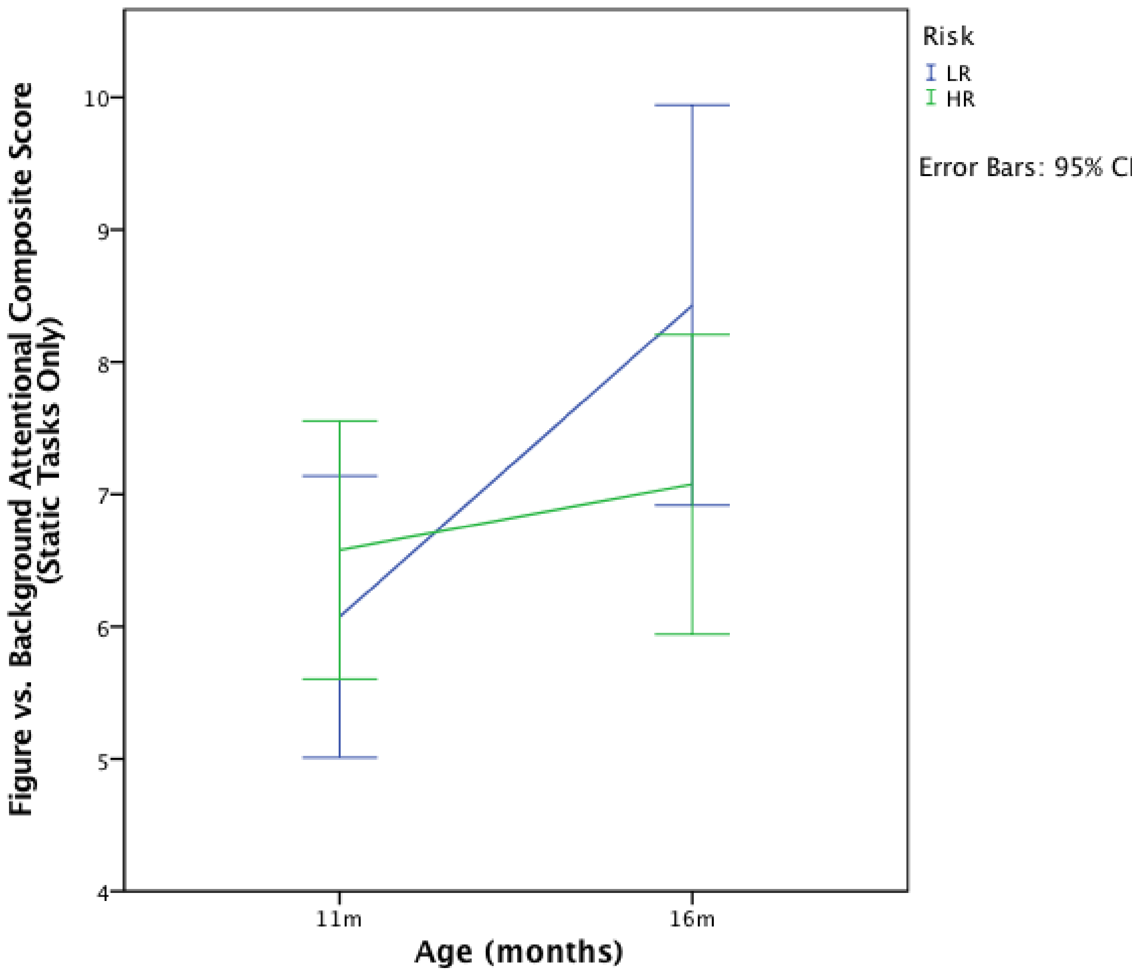

Figure 13. Risk status by age on figure vs. background attentional composite score for static tasks.

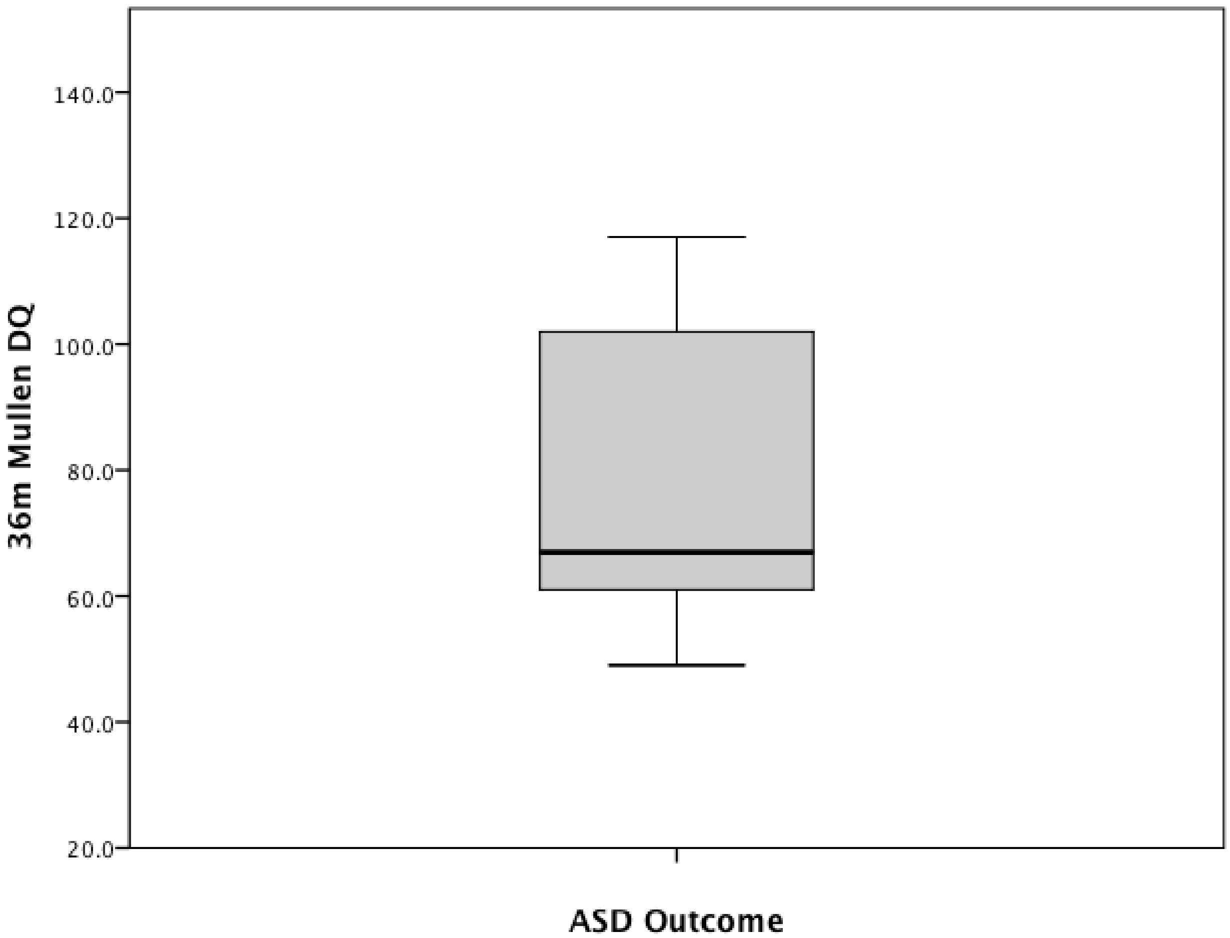

Figure 14. Boxplot of ASD infants' Mullen Developmental Quotient (DQ) at 36 months.

7.0 BIBLIOGRAPHY

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders (DSM-5®)*. American Psychiatric Pub.

Aslin, R. N. (1987). Visual and auditory development in infancy. In J.D. Osoksky (Ed.), *Handbook of Infant Development*, 5-97.

Aylward, G. P. (2002). Cognitive and neuropsychological outcomes: more than IQ scores. *Mental retardation and developmental disabilities research reviews, 8*(4), 234-240.

Aylward, G. P., Pfeiffer, S. I., Wright, A., & Verhulst, S. J. (1989). Outcome studies of low birth weight infants published in the last decade: a metaanalysis. *The Journal of pediatrics*, *115*(4), 515-520.

Bernabei, P., Camaigni, L., & Levi, G. (1998). An Evaluation of Early Development in Children with Autism and Pervasive Developmental Disorders from Home Movies: Preliminary Findings. *Autism : the international journal of research and practice, 2*(3), 243-258.

Bornstein, M. H., & Sigman, M. D. (1986). Continuity in mental development from infancy. *Child development*, 251-274.

Cassia, V. M., Turati, C., & Simion, F. (2004). Can a Nonspecific Bias toward Top-Heavy Patterns Explain Newborns' Face Preference? *Psychological Science, 15*(6), 379-383.

Chawarska, K., Macari, S., & Shic, F. (2013). Decreased spontaneous attention to social scenes in 6-month-old infants later diagnosed with autism spectrum disorders. *Biological psychiatry*, *74*(3), 195-203.

Chawarska, K., Volkmar, F., & Klin, A. (2010). Limited attentional bias for faces in toddlers with autism spectrum disorders. *Archives of general psychiatry*, *67*(2), 178-185.

Christensen DL, Baio J, Braun KV, et al. Prevalence and Characteristics of Autism Spectrum Disorder Among Children Aged 8 Years — Autism and Developmental Disabilities Monitoring Network, 11 Sites, United States, 2012. MMWR Surveill Summ 2016;65(No. SS-3)(No. SS-3):1–23.

Cohen, R. L., & Gowen, A. (1978). Recall and recognition of order and item information in probed running memory, as a function of IQ. *Intelligence*, *2*(4), 343-352.

Colombo, J. (1993). *Infant cognition: Predicting later intellectual functioning* (Vol. 5). Sage publications.

Colombo, J. (2001). Recent advances in infant cognition: implications for long-chain polyunsaturated fatty acid supplementation studies. *Lipids*, *36*(9), 919-926.

Colombo, J. (2002). Infant attention grows up: The emergence of a developmental cognitive neuroscience perspective. *Current Directions in Psychological Science*, *11*(6), 196-200.

Colombo, J., Freeseman, L. J., Coldren, J. T., & Frick, J. E. (1995). Individual differences in infant fixation duration: Dominance of global versus local stimulus properties. *Cognitive Development*, *10*(2), 271-285.

Colombo, J., Harlan, J. E., & Mitchell, D. W. (1999). Look duration in infancy: Evidence for a triphasic course. In *Poster presented at the meeting of the Society for research in Child Development*.

Colombo, J., & Janowsky, J. S. (1998). A cognitive neuroscience approach to individual differences in infant cognition. *Cognitive neuroscience of attention: A developmental perspective*, 363-392.

Colombo, J., & Mitchell, D. W. (1990). Individual and developmental differences in infant visual attention. *Individual differences in infancy*, 193-227.

Colombo, J., Mitchell, D. W., Coldren, J. T., & Freeseman, L. J. (1991). Individual differences in infant visual attention: are short lookers faster processors or feature processors?. *Child development*, *62*(6), 1247-1257.

Colombo, J., Mitchell, D. W., & Horowitz, F. D. (1988). Infant visual attention in the paired-comparison paradigm: Test-retest and attention-performance relations. *Child development*, 1198-1210.

Colombo, J., Mitchell, D. W., O'Brien, M., & Horowitz, F. D. (1987). The stability of visual habituation during the first year of life. *Child Development*, 474-487.

Colombo, J., Richman, W. A., Shaddy, D. J., Follmer Greenhoot, A., & Maikranz, J. M. (2001). Heart rate-defined phases of attention, look duration, and infant performance in the paired-comparison paradigm. *Child development*, *72*(6), 1605-1616.

Colombo, J., Shaddy, D. J., Richman, W. A., Maikranz, J. M., & Blaga, O. M. (2004). The developmental course of habituation in infancy and preschool outcome. *Infancy*, *5*(1), 1-38.

Constantino, J. N., & Gruber, C. P. (2007). *Social responsiveness scale (SRS)*. Los Angeles, CA: Western Psychological Services.

Corbett, S. S., & Drewett, R. F. (2004). To what extent is failure to thrive in infancy associated with poorer cognitive development? A review and meta-analysis. *Journal of child Psychology and Psychiatry*, *45*(3), 641-654.

Courage, M. L., Reynolds, G. D., & Richards, J. E. (2006). Infants' attention to patterned stimuli: Developmental change from 3 to 12 months of age. *Child development*, *77*(3), 680-695.

Drotar, D., & Sturm, L. (1988). Prediction of intellectual development in young children with early histories of nonorganic failure-to-thrive. *Journal of Pediatric Psychology*, *13*(2), 281-296.

Elison, J. T., Sasson, N. J., Turner-Brown, L. M., Dichter, G. S., & Bodfish, J. W. (2012). Age trends in visual exploration of social and nonsocial information in children with autism. *Research in autism spectrum disorders,6*(2), 842-851.

Elmer, E., Gregg, G. S., & Ellison, P. (1969). Late of the" Failure to Thrive" Syndrome. *Clinical Pediatrics*, *8*(10), 584-589.

Elsabbagh, M., Bedford, R., Senju, A., Charman, T., Pickles, A., Johnson, M. H., & BASIS Team. (2014). What you see is what you get: contextual modulation of face scanning in typical and atypical development. *Social cognitive and affective neuroscience*, *9*(4), 538-543.

Elsabbagh, M., Fernandes, J., Webb, S. J., Dawson, G., Charman, T., Johnson, M. H., & British Autism Study of Infant Siblings Team. (2013). Disengagement of visual attention in infancy is associated with emerging autism in toddlerhood. *Biological Psychiatry*, *74*(3), 189-194.

Elsabbagh, M., Gliga, T., Pickles, A., Hudry, K., Charman, T., Johnson, M. H., & BASIS Team. (2013). The development of face orienting mechanisms in infants at-risk for autism. *Behavioural Brain Research*, *251*, 147-154.

Escobar, G. J., Littenberg, B., & Petitti, D. B. (1991). Outcome among surviving very low birthweight infants: a meta-analysis. *Archives of Disease in Childhood*, *66*(2), 204-211.

Fagan, J. F. (1972). Infants' recognition memory for faces. *Journal of experimental child psychology*, *14*(3), 453-476.

Fagan, J. F. (1984). The relationship of novelty preferences during infancy to later intelligence and later recognition memory. *Intelligence, 8*(4), 339-346.

Fagan, J. F. (1990). The Paired-Comparison Paradigm and Infant Intelligence. *Annals of the New York Academy of Sciences, 608*(1), 337-364.

Fagan, J. F., & Detterman, D. K. (1992). The Fagan test of infant intelligence: a technical summary. *Journal of Applied Developmental Psychology*, *13*(2), 173-193.

Fagan, J. F., & Singer, L. T. (1983). Infant recognition memory as a measure of intelligence. *Advances in infancy research*.

Fagan, J. F., Singer, L. T., Montie, J. E., & Shepherd, P. A. (1986). Selective screening device for the early detection of normal or delayed cognitive development in infants at risk for later mental retardation. *Pediatrics, 78*(6), 1021-1026.

Fantz, R. L. (1964). Visual experience in infants: Decreased attention to familiar patterns relative to novel ones. *Science, 146*(3644), 668-670.

Farroni, T., Menon, E., Rigato, S., & Johnson, M. H. (2007). The perception of facial expressions in newborns. *European Journal of Developmental Psychology*, *4*(1), 2-13.

Fenson, L., Bates, E., Dale, P. S., Hartung, J. P., Pethick, S. J., Reilly, J. S., ... & Thal, D. J. (1996). *The MacArthur communicative development inventories*. Singular publishing Group, Incorporated.

Frazier, T. W., Klingemier, E. W., Beukemann, M., Speer, L., Markowitz, L., Parikh, S., ... & Ahuja, V. (2016). Development of an objective autism risk index using remote eye tracking. *Journal of the American Academy of Child & Adolescent Psychiatry*, *55*(4), 301-309.

Frick, J. E., Colombo, J., & Saxon, T. F. (1999). Individual and developmental differences in disengagement of fixation in early infancy. *Child Development*,*70*(3), 537-548.

Gastgeb, H. Z., Dundas, E. M., Minshew, N. J., & Strauss, M. S. (2012). Category formation in autism: can individuals with autism form categories and prototypes of dot patterns?. *Journal of autism and developmental disorders*,*42*(8), 1694-1704.

Gastgeb, H. Z., Wilkinson, D. A., Minshew, N. J., & Strauss, M. S. (2011). Can individuals with autism abstract prototypes of natural faces?. *Journal of autism and developmental disorders*, *41*(12), 1609-1618.

Goldsmith, H., & Rothbart, M. (1996). Prelocomotor and locomotor Laboratory Temperament Assessment Battery (Lab-TAB; version 3.0, Technical Manual). *Madison: University of Wisconsin, Department of Psychology*.

Goren, C. C., Sarty, M., & Wu, P. Y. (1975). Visual following and pattern discrimination of face-like stimuli by newborn infants. *Pediatrics, 56*(4), 544-549.

Hack, M., Breslau, N., Aram, D., Weissman, B., Klein, N., & Borawski-Clark, E. (1992). The effect of very low birth weight and social risk on neurocognitive abilities at school age. *Journal of Developmental & Behavioral Pediatrics*, *13*(6), 412-420.

Hall, S. S., Lightbody, A. A., & Reiss, A. L. (2008). Compulsive, self-injurious, and autistic behavior in children and adolescents with fragile X syndrome. *American Journal on Mental Retardation*, *113*(1), 44-53.

Harris, S. W., Hessl, D., Goodlin-Jones, B., Ferranti, J., Bacalman, S., Barbato, I., ... & Hagerman, R. J. (2008). Autism profiles of males with fragile X syndrome. *American Journal on Mental Retardation*, *113*(6), 427-438.

Hellendoorn, A., Wijnroks, L., & Leseman, P. P. (2015). Unraveling the nature of autism: finding order amid change. *Frontiers in psychology*, *6*.

Hood, B. M. (1995). Shifts of visual attention in the human infant: A neuroscientific approach. *Advances in infancy research*, *9*, 163-216.

Hoy, E. A., Bill, J. M., & Sykes, D. H. (1988). Very low birthweight: a long-term developmental impairment?. *International Journal of Behavioral Development*, *11*(1), 37-67.

Ibanez, L. V., Messinger, D. S., Newell, L., Lambert, B., & Sheskin, M. (2008). Visual disengagement in the infant siblings of children with an autism spectrum disorder (ASD). *Autism*, *12*(5), 473-485.

Jacobson, S. W., Jacobson, J. L., Sokol, R. J., Martier, S. S., & Chiodo, L. M. (1996). New evidence for neurobehavioral effects of in utero cocaine exposure. *The Journal of pediatrics*, *129*(4), 581-590.

Jankowski, J. J., & Rose, S. A. (1997). The distribution of visual attention in infants. *Journal of Experimental Child Psychology*, *65*(2), 127-140.

Jankowski, J. J., Rose, S. A., & Feldman, J. F. (2001). Modifying the distribution of attention in infants. *Child Development*, *72*(2), 339-351.

Johnson, M. H., Dziurawiec, S., Bartrip, J., & Morton, J. (1992). The effects of movement of internal features on infants' preferences for face-like stimuli. *Infant Behavior and Development*, *15*(1), 129-136.

Johnson, M. H. & Morton, J. (1991). *Biology and cognitive development: The case of face recognition*, Oxford (UK) and Cambridge (USA): Blackwell.

Jones, W., & Klin, A. (2013). Attention to eyes is present but in decline in 2-6-month-old infants later diagnosed with autism. *Nature*, *504*(7480), 427-431.

Jones, E. J. H., Venema, K., Earl, R., Lowy, R., Barnes, K., Estes, A., ... & Webb, S. J. (2016). Reduced engagement with social stimuli in 6-month-old infants with later autism spectrum disorder: a longitudinal prospective study of infants at high familial risk. *Journal of neurodevelopmental disorders*, *8*(1), 1.

Kéri, S., Kálmán, J., Kelemen, O., Benedek, G., & Janka, Z. (2001). Are Alzheimer's disease patients able to learn visual prototypes?. *Neuropsychologia*, *39*(11), 1218-1223.

Kleinman, J. M., Ventola, P. E., Pandey, J., Verbalis, A. D., Barton, M., Hodgson, S., ... & Fein, D. (2008). Diagnostic stability in very young children with autism spectrum disorders. *Journal of autism and developmental disorders*, *38*(4), 606-615.

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual fixation patterns during viewing of naturalistic social situations as predictors of social competence in individuals with autism. *Archives of general psychiatry, 59*(9), 809-816.

Kopp, C. B., & McCall, R. B. (1982). Predicting later mental performance for normal, at-risk, and handicapped infants. *Life-span development and behavior*.

Kwon, M. K., Luck, S. J., & Oakes, L. M. (2014). Visual Short‐Term Memory for Complex Objects in 6‐and 8‐Month‐Old Infants. *Child development*, *85*(2), 564-577.

Landry, R., & Bryson, S. E. (2004). Impaired disengagement of attention in young children with autism. *Journal of Child Psychology and Psychiatry*,*45*(6), 1115-1122.

Lawson, K. R., & Ruff, H. A. (2004a). Early focused attention predicts outcome for children born prematurely. *Journal of Developmental & Behavioral Pediatrics, 25*(6), 399-406.

Lawson, K. R., & Ruff, H. A. (2004b). Early attention and negative emotionality predict later cognitive and behavioural function. *International Journal of Behavioral Development*, *28*(2), 157-165.

Lord, C., Rutter, M., DiLavore, P. C., & Risi, S. (1999). Autism diagnostic observation schedule-WPS (ADOS-WPS). *Los Angeles, CA: Western Psychological Services*.

Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: a revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of autism and developmental disorders*, *24*(5), 659-685.

Maestro, S., Casella, C., Milone, A., Muratori, F., & Palacio-Espasa, F. (1999). Study of the onset of autism through home movies. *Psychopathology, 32*(6), 292-300.

McCall, R. B., & Carriger, M. S. (1993). A meta-analysis of infant habituation and recognition memory performance as predictors of later IQ. *Child development*, 57-79.

McCleery, J. P., Akshoomoff, N., Dobkins, K. R., & Carver, L. J. (2009). Atypical face versus object processing and hemispheric asymmetries in 10-month-old infants at risk for autism. *Biological psychiatry, 66*(10), 950-957. doi: 10.1016/j.biopsych.2009.07.031

Minshew, N. J., & Goldstein, G. (2001). The pattern of intact and impaired memory functions in autism. *Journal of Child Psychology and Psychiatry*,*42*(08), 1095-1101.

Minshew, N. J., & Williams, D. L. (2007). The new neurobiology of autism: cortex, connectivity, and neuronal organization. *Archives of neurology*, *64*(7), 945-950.

Mottron, L., Dawson, M., Soulières, I., Hubert, B., & Burack, J. (2006). Enhanced perceptual functioning in autism: an update, and eight principles of autistic perception. *Journal of autism and developmental disorders, 36*(1), 27-43.

Mullen, E. M. (1995). *Mullen scales of early learning* (pp. 58-64). Circle Pines, MN: AGS.

Mundy, P., & Neal, A. R. (2000). Neural plasticity, joint attention, and a transactional social-orienting model of autism. *International review of research in mental retardation, 23*, 139-168.

Osterling, J., & Dawson, G. (1994). Early recognition of children with autism: a study of first birthday home videotapes. *Journal of autism and developmental disorders*, *24*(3), 247-257.

Ozonoff, S., Iosif, A. M., Baguio, F., Cook, I. C., Hill, M. M., Hutman, T., ... & Steinfeld, M. B. (2010). A prospective study of the emergence of early behavioral signs of autism. *Journal of the American Academy of Child & Adolescent Psychiatry*, *49*(3), 256-266.

Ozonoff, S., Macari, S., Young, G. S., Goldring, S., Thompson, M., & Rogers, S. J. (2008). Atypical object exploration at 12 months of age is associated with autism in a prospective sample. *Autism*, *12*(5), 457-472.

Ozonoff, S., Young, G. S., Carter, A., Messinger, D., Yirmiya, N., Zwaigenbaum, L., ... & Hutman, T. (2011). Recurrence risk for autism spectrum disorders: a Baby Siblings Research Consortium study. *Pediatrics*,*128*(3), e488-e495.

Perlman, J. M. (2003). The genesis of cognitive and behavioral deficits in premature graduates of intensive care. *Minerva pediatrica*, *55*(2), 89-101.

Pierce, K., Conant, D., Hazin, R., Stoner, R., & Desmond, J. (2011). Preference for geometric patterns early in life as a risk factor for autism. *Archives of general psychiatry*, *68*(1), 101-109. doi: 10.1001/archgenpsychiatry.2010.113

Posner, M. I. (1995). Attention in cognitive neuroscience: an overview. In M. Gazzaniga (Ed.), *The cognitive neurosciences*, 615-624.

Reynolds, G. D. (2015). Infant visual attention and object recognition. *Behavioural brain research*, *285*, 34-43.

Reynolds, G. D., Courage, M. L., & Richards, J. E. (2013). The development of attention. *Oxford Handbook of Cognitive Psychology*, 1000-1013.

Reynolds, G., & Richards, J. E. (2007). A Developmental Psychophysiological Perspective. *Developmental psychophysiology: Theory, systems, and methods*, 173.

Richards, J. E. (2001). Attention in young infants: A developmental psychophysiological perspective. *Handbook of developmental cognitive neuroscience*, 321-338.

Richards, J. E. (2010). The development of attention to simple and complex visual stimuli in infants: Behavioral and psychophysiological measures. *Developmental Review*, *30*(2), 203-219.

Richards, J. E., & Casey, B. J. (1990). Infant visual recognition memory performance as a function of heart rate defined phases of attention. *Infant Behavior and Development*, *13*, 585.

Richards, J. E., & Casey, B. J. (1991). Heart rate variability during attention phases in young infants. *Psychophysiology*, *28*(1), 43-53.

Richards, J. E., & Casey, B. J. (1992). Development of sustained visual attention in the human infant. *Attention and information processing in infants and adults: Perspectives from human and animal research*, 30-60.

Richards, J. E., & Cronise, K. (2000). Extended visual fixation in the early preschool years: Look duration, heart rate changes, and attentional inertia. *Child Development*, *71*(3), 602-620.

Richards, J. E., Reynolds, G. D., & Courage, M. L. (2010). The neural bases of infant attention. *Current Directions in Psychological Science*, *19*(1), 41-46.

Reynolds, G., & Richards, J. E. (2007). A Developmental Psychophysiological Perspective. *Developmental psychophysiology: Theory, systems, and methods*, 173.

Roberts, J. E., Hatton, D. D., Long, A. C., Anello, V., & Colombo, J. (2012). Visual attention and autistic behavior in infants with fragile X syndrome. *Journal of autism and developmental disorders*, *42*(6), 937-946.

Rogers, S. J. (2009). What are infant siblings teaching us about autism in infancy?. *Autism Research*, *2*(3), 125-137.

Rose, S. A. (1980). Enhancing visual recognition memory in preterm infants. *Developmental Psychology*, *16*(2), 85.

Rose, S. A. (1983). Differential rates of visual information processing in full-term and preterm infants. *Child development*, 1189-1198.

Rose, S. A., & Feldman, J. F. (2000, January). The relation of very low birth weight to basic cognitive skills in infancy and childhood. In *The effects of early adversity on neurobehavioral development. The Minnesota symposia on child psychology* (Vol. 31, pp. 31-60).

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2004). Infant visual recognition memory. *Developmental Review*, *24*(1), 74-100.

Rose, S. A., Feldman, J. F., & Jankowski, J. J. (2012). Implications of infant cognition for executive functions at age 11. *Psychological science*, *23*(11), 1345-1355.

Rose, S. A., Feldman, J. F., Wallace, I. F., & McCarton, C. (1989). Infant visual attention: Relation to birth status and developmental outcome during the first 5 years. *Developmental Psychology*, *25*(4), 560.

Rose, S. A., Gottfried, A. W., & Bridger, W. H. (1978). Cross-modal transfer in infants: Relationship to prematurity and socioeconomic background. *Developmental Psychology*, *14*(6), 643.

Rose, S. A., Gottfried, A. W., & Bridger, W. H. (1979). Effects of haptic cues on visual recognition memory in fullterm and preterm infants. *Infant Behavior and Development, 2*, 55-67.

Rose, S. A., & Orlian, E. K. (2001). Visual information processing. *Biobehavioral Assessment of the Infant (Singer LT, Zeskind PS, eds). New York: Guilford*, *274*, 292.

Rose, D. H., Slater, A., & Perry, H. (1986). Prediction of childhood intelligence from habituation in early infancy. *Intelligence*, *10*(3), 251-263.

Rothbart, M. K., Posner, M. I., & Boylan, A. (1990). Regulatory mechanisms in infant development. *Advances in psychology*, *69*, 47-66.

Ruff, H. A. (1986). Attention and organization of behavior in high-risk infants. *Journal of Developmental & Behavioral Pediatrics*, *7*(5), 298-301.

Ruff, H. A., & Capozzoli, M. C. (2003). Development of attention and distractibility in the first 4 years of life. *Developmental psychology*, *39*(5), 877.

Ruff, H. A., McCarton, C., Kurtzberg, D., & Vaughan Jr, H. G. (1984). Preterm infants' manipulative exploration of objects. *Child development*, 1166-1173.

Ruff, H.A., & Rothbart, M.K. (1996). *Attention in early development.* New York: Oxford University Press.

Ruff, H. A., & Saltarelli, L. M. (1993). Exploratory play with objects: Basic cognitive processes and individual differences. *New Directions for Child and Adolescent Development*, *1993*(59), 5-16.

Sasson, N. J., Elison, J. T., Turner-Brown, L. M., Dichter, G. S., & Bodfish, J. W. (2011). Brief report: Circumscribed attention in young children with autism. *Journal of Autism and Developmental Disorders*, *41*(2), 242-247.

Shic, F., Macari, S., & Chawarska, K. (2014). Speech disturbs face scanning in 6-month-old infants who develop autism spectrum disorder. *Biological psychiatry*, *75*(3), 231-237.

Sigman, M. D., Cohen, S. E., Beckwith, L., & Parmelee, A. H. (1986). Infant attention in relation to intellectual abilities in childhood. *Developmental Psychology, 22*(6), 788.

Singer, L. T., & Fagan, J. F. (1984). Cognitive development in the failure-to-thrive infant: a three-year longitudinal study. *Journal of Pediatric Psychology*,*9*(3), 363-384.

Singer, L. T., Arendt, R., Fagan, J., Minnes, S., Salvator, A., Bolek, T., & Becker, M. (1999). Neonatal visual information processing in cocaine-exposed and non-exposed infants. *Infant Behavior and Development*, *22*(1), 1-15.

Singer, L. T., Eisengart, L. J., Minnes, S., Noland, J., Jey, A., Lane, C., & Min, M. O. (2005). Prenatal cocaine exposure and infant cognition. *Infant Behavior and Development*, *28*(4), 431-444.

Struthers, J. M., & Hansen, R. L. (1992). Visual recognition memory in drug-exposed infants. *Journal of Developmental & Behavioral Pediatrics*, *13*(2), 108-111.

Swettenham, J., Baron-Cohen, S., Charman, T., Cox, A., Baird, G., Drew, A., ... & Wheelwright, S. (1998). The frequency and distribution of spontaneous attention shifts between social and nonsocial stimuli in autistic, typically developing, and nonautistic developmentally delayed infants. *Journal of Child Psychology and Psychiatry*, *39*(05), 747-753.

Tamis-LeMonda, C. S., & Bornstein, M. H. (1989). Habituation and maternal encouragement of attention in infancy as predictors of toddler language, play, and representational competence. *Child Development*, 738-751.

Turati, C., Valenza, E., Leo, I., & Simion, F. (2005). Three-month-olds' visual preference for faces and its underlying visual processing mechanisms. *Journal of Experimental Child Psychology, 90*(3), 255-273.

Webb, S. J., Jones, E. J., Merkle, K., Namkung, J., Toth, K., Greenson, J., ... & Dawson, G. (2010). Toddlers with elevated autism symptoms show slowed habituation to faces. *Child Neuropsychology*, *16*(3), 255-278.

Webb, S. J., Neuhaus, E., & Faja, S. (2016). Face perception and learning in autism spectrum disorders. *The Quarterly Journal of Experimental Psychology*, 1-17.

Williams, D. L., Goldstein, G., & Minshew, N. J. (2005). Impaired memory for faces and social scenes in autism: clinical implications of memory dysfunction. *Archives of clinical neuropsychology*, *20*(1), 1-15.

Williams, D. L., Goldstein, G., & Minshew, N. J. (2006). Neuropsychologic functioning in children with autism: Further evidence for disordered complex information-processing. *Child Neuropsychology*, *12*(4-5), 279-298.

Zwaigenbaum, L., Bryson, S., Rogers, T., Roberts, W., Brian, J., & Szatmari, P. (2005). Behavioral manifestations of autism in the first year of life. *International journal of developmental neuroscience*, *23*(2), 143-152.