Social attention in young children with autism spectrum disorder: Investigating cross-contextual gaze behaviours, and their relationship to autism severity, cognitive skills, and social functioning

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Statement of Originality

This is to certify that to the best of my knowledge; the content of this thesis is my own work. This thesis has not been submitted for any degree or other purposes.

I certify that the intellectual content of this thesis is the product of my own work and that all the assistance received in preparing this thesis and sources have been acknowledged.

Zahava Ambarchi

Authorship Attribution Statement

Chapter 2 of this thesis is published as **Ambarchi, Z.,** Boulton, K.A., Thapa, R. et al. Evidence of a reduced role for circumscribed interests in the social attention patterns of children with Autism Spectrum Disorder. J Autism Dev Disord (2022). https://doi.org/10.1007/s10803-022-05638-4

Prof Adam Guastella and I designed this study. I was involved in collecting the data together with other co-authors listed on the publication. I extracted and analysed the data and wrote the draft manuscript. Prof Guastella, Dr Boulton, and other co-authors reviewed and provided substantial input in finalising the manuscript for submission.

This thesis contains material published in Sasson, N.J., Touchstone, E.W. Visual Attention to Competing Social and Object Images by Preschool Children with Autism Spectrum Disorder. J Autism Dev Disord **44**, 584–592 (2014). https://doi.org/10.1007/s10803-013-1910-z This is Figure 2.1, which appears on page 53 of section 2.2.3. Prof Guastella contacted the corresponding author for this article to seek permission for use of the experimental task in the design of this study. The figure is from the experimental task. The corresponding author, Prof Noah Sasson, provided permission to include the published material and is listed as a co-author of the published manuscript described in Chapter 2.

The study described in Chapter 3 was supported by several people. Prof Adam Guastella, Prof Joanne Arciuli and I designed the study. I developed the scripts for the study and together with other researchers, was involved in data collection. A substantial portion of data was collected by researchers in the CAN Research team, which is led by Prof Guastella. These researchers were Dr Rinku Thapa, Dr Marilena DeMayo, Emma Guastella, and Izabella Pokorski. Specifically, Dr

Rinku Thapa, Emma Guastella and Izabella Pokorski were involved in administering the ADOS-2 assessments, and Dr Rinku Thapa assisted with collecting the eye-tracking data. Dr Nigel Chen provided advice for data analysis, along with Prof Guastella. I extracted and analysed the data and drafted the chapter. Prof Guastella and Dr Boulton provided feedback on the chapter.

Chapter 4 of this thesis was designed by Prof Adam Guastella and I. As a portion of the data in this study was initially collected for Chapter 3, the CAN Research members mentioned above contributed in this regard to this study. In addition, Qiong Wu (Lisa), Taylor Lowry and Jian Sun (Carter), higher degree research students of Prof Guastella, were primarily involved in the extraction and analysis of data collected in the ADOS-2 assessments. I analysed the data set as a whole, with guidance from Prof Guastella. I drafted the chapter. Prof Guastella and Dr Boulton provided feedback on the chapter.

In addition to the statements above, in cases where I am not the corresponding author of a published item, permission to include the published material has been granted by the corresponding author.

Zahava Ambarchi

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As supervisor for the candidature upon which this thesis is based, I can confirm that the authorship attribution statements above are correct.

Prof Adam Guastella

Signature

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Abstract

Social communication and interaction challenges are characteristic of autism spectrum disorder (ASD). Social attention has emerged to be an important behavioural phenotype in ASD, with accumulating evidence suggesting associations with social functioning and developmental outcomes. However, research gaps remain concerning the nature of social attention, the variability demonstrated across different experimental tasks and social contexts, and the ecologically validity of research methods. This thesis aimed to address these substantive and methodological issues by examining social attention patterns in a young cohort of autistic children, and their age-matched neurotypical peers, across three experimental contexts: 1) a traditional, eye-tracking task with static stimuli, 2) a novel, dynamic eye-tracking task incorporating shared book reading (SBR), and 3) an evaluation of the association in social attention across the two eye-tracking tasks and a play-based social interaction task.

In Chapter 2, the influence of circumscribed interests (CI) on social attention patterns was investigated. The results of this study suggested there to be a reduced role for CIs and atypical attention patterns in both social and non-social domains. In Chapter 3, a novel SBR task was developed as a dynamic, ecologically relevant eye-tracking task designed to assess social and joint attention behaviours. Results indicated reduced social and joint attention behaviours, in conjunction with increased attention to non-salient background objects in autistic children. Associations between reduced social attention and poorer social functioning and cognitive skills were also evident in this cohort. In Chapter 4, the social attention patterns of the autistic cohort as measured by the two previous eye tracking tasks were correlated with these patterns in a live, play-based social interaction task between a researcher and the autistic child. Cross-contextual associations in social attention between the social interaction and dynamic tasks, and the dynamic

and static tasks were observed. In contrast, there was no significant association in social attention patterns between the social interaction and static tasks. These outcomes contribute new insights into the social attention behaviours of autistic children, and evidence in favor of examining these behaviours in ecologically relevant contexts. They also contribute to evidence associating social attention with autism symptomatology and cognitive functioning. Ultimately, the outcomes of this research may improve our understanding of the needs of autistic children across social, cognitive and adaptive functioning domains.

Publications associated with this thesis

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List of Tables

List of Figures

List of Abbreviations

Abbreviation	Definition
ADHD	Attention Deficit Hyperactivity Disorder
ADOS-2	Autism Diagnostic Observation Schedule – Second Edition
AIWH	Australian Institute of Health and Welfare
ANOVA	Analysis Of Variance
AOIs	Areas of Interest
AI	Artificial Intelligence
APA	American Psychiatric Association
ASD	Autism Spectrum Disorder
BMC	Brain and Mind Centre
BO	Background Objects
CAN Research	Clinic for Autism and Neurodevelopment Research
CARS-2	Childhood Autism Rating Scale – Second Edition
CIs	Circumscribed Interests
CSS	Calibrated Severity Scores
DB	Dyadic Bid
DQ	Developmental Quotient
DSM	Diagnostic and Statistical Manual of Mental Disorders
DSM-5-TR	Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition, Text Revision
DV	Dependent Variable

FK	Flesch-Kincaid
HAI	High Autism Interest
HREC	Human Research Ethics Committee
JA	Joint Attention
LAI	Low Autism Interest
Leiter-3	Leiter International Performance Scale - Third Edition
LIWC	Linguistic Inquiry and Word Count
NVDQ	Non-Verbal Developmental Quotient
NVIQ	Non-Verbal Intellectual Quotient
M-CHAT	Modified Checklist for Autism in Toddlers
MSEL	Mullen Scales of Early Learning
P-CR	Pupil-Corneal Reflection
PPVT-4	Peabody Picture Vocabulary Test – Fourth Edition
RL	Receptive Language
RM-ANOVA	Repeated Measures Analysis Of Variance
RRBs	Restricted Interests and Repetitive Behaviours
SA	Social Affect
SBR	Shared Book Reading
SCI	Social Communication and Interaction
SI	Supplementary Information
SRS-2	Social Responsiveness Scale - Second Edition
ToM	Theory of Mind

TYP	Neurotypical/Typically Developing
VIQ	Verbal Intellectual Quotient
WC	Word Count
WPS	Words Per Sentence

Table of contents

1. General Introduction

1.1. Defining the Importance of Social Attention in Autism Research

Life is a social experience, and how we relate to others has been of long-standing interest in research investigating human behaviour. Our social behaviours are often guided by our attention to social cues in our environment, such as the faces and eyes of others (Klein et al., 2009; Salley & Colombo, 2016). Social attention is a term commonly used to signify the visual attention and information processing mechanisms guiding our social behaviour (Salley & Colombo, 2016), 2016), providing valuable information about the familiarity, direction of attention, affect, and intentions of others (Johnson et al., 2015; Jording et al., 2019; Nummenmaa & Calder, 2009; Young, 1998). Social attention is considered to have an important role in the development of social communication skills and functioning adaptively within a social group (Dawson et al., 2012; Pascalis et al., 2014).

The innate salience of social attention is seen in the earliest stage of life, with studies demonstrating infants' unique predisposition to orient to and understand the information provided by faces and eyes (Johnson, 2005; Pons et al., 2019; Simpson et al., 2019). The eyes have often been metaphorically described as the "windows to the mind", divulging a wealth of information on the emotion, intention, and motivations of others (Baron-Cohen, 2017; Grossmann, 2017; Khalid et al., 2016). Eye contact plays a vital bi-directional role in the information processing mechanisms related to the shared awareness of others, guiding our communication and social interactions throughout our lifespan (Hessels, 2020; Holleman et al., 2020; Jarick & Bencic, 2019; Langton et al., 2000; Mundy & Bullen, 2022). The uniqueness of this communicative feature in human behaviour and interactions has considerable evolutionary, developmental, neurological, and genetic underpinnings (Baron-Cohen, 2017; Grossmann, 2017).

Autism spectrum disorder (ASD) is a neurodevelopmental condition partly defined by the difficulties in social communication and interaction experienced across the lifespan (American Psychiatric Association, 2022). Atypical social attention, commonly reflected in reduced attention to the faces and eyes of others, has been widely reported in autistic populations (Bast et al., 2018; Chita-Tegmark, 2016b; Dawson et al., 2004; Frazier et al., 2017; Hedger et al., 2020; Ji et al., 2018; Wagner et al., 2018). Considering its importance to social and adaptive functioning, understanding the nature of social attention and its association with broader social behaviours is of paramount research interest, with developments potentially contributing to improved long-term outcomes in this population.

1.2. Historical Roots and Diagnosis of ASD

In 1943, child psychiatrist Leo Kanner published the first and his most seminal research article, in which he described the case histories and behaviours of 11 children who appeared to be born without the capacity to orient to and socially engage with others in a manner consistent with the typical development of children (Harris, 2018; Kanner, 1943). Along with poorer social attention, these children exhibited other atypical behaviours, including restricted interests and an insistence of sameness, repetitive behaviours [such as hand flapping or spinning], and delays in language development (Kanner, 1943). Kanner (1943) assigned the diagnostic label of ‘early infantile autism’ to these children (Kanner, 1943, 1944). Subsequent years saw other prominent clinical-researchers such as Robinson and Vitale (1954) and Hans Asperger (1979) address considerations such as the severity of social detachment, interest in highly specific objects or topics, and sensory and cognitive processing anomalies (Baron-Cohen, 2015; Verhoeff, 2013). Over the years and iterative editions of the Diagnostic and Statistical Manual of Mental Disorders (DSM), the diagnostic term has evolved in its definition, symptomatology, and nosology to what is now considered to be a neurodevelopmental disorder termed ASD (Baron-Cohen, 2015; Verhoeff, 2013). Nevertheless, the current DSM Fifth Edition, Text Revision (DSM-5-TR) remains fundamentally true to Kanner's original observations, with ASD encompassing two broad behavioural domains characterised by 1) impairments in social communication and interaction, and 2) restricted and repetitive behaviours, activities, or interests (American Psychiatric Association, 2022; Harris, 2018).

To receive an ASD diagnosis, social communication and interaction (SCI) impairments must be observed across multiple settings (American Psychiatric Association, 2022). These behaviours may include: a lack of social and emotional reciprocity; a perceived lack of desire to initiate or respond to social interactions; reduced and poorly integrated eye contact with other non-verbal communication techniques such as gestures, which also can be poorly understood or used; and difficulty developing and maintaining friendships or understanding the nature of different type of relationships (American Psychiatric Association, 2022). In addition, at least two indications of restricted or repetitive behaviours or interests (termed RRBs), must be evident; for example, stereotypic or repetitive patterns of movement or speech; an insistence on sameness or abnormal levels of distress associated with transitions or unanticipated changes; an intense focus on circumscribed interests; and an unusual interest in, or aversion to, sensory stimuli (American Psychiatric Association, 2022).

1.2.1. Symptom Heterogeneity, Screening, and Diagnosis

The heterogeneity in symptom presentation is well-noted in the literature (Del Bianco et al., 2020; Masi et al., 2017; Pickles et al., 2020). There is considerable inter- and intra-individual variability in the combinations of how or which of these behaviours are expressed across different contexts, throughout development, and in in their severity (Masi et al., 2017; Pickles et al., 2020;

Rice et al., 2012; Tager-Flusberg et al., 2017). For example, one child with ASD may present with severe deficits in verbal communication skills but a relative ease in managing task transitions, while a different child may have advanced communication skills, however, would rather engage in highly specific non-social activities than make friends. The expression of these behaviours may also change over time for a range of reasons, including idiopathic changes associated with development, or as a response to treatment interventions (Lewis & van Schalkwyk, 2019; Miranda et al., 2022; Salomone et al., 2019; Van Den Bergh et al., 2014; Zwaigenbaum et al., 2019). There has also been research to suggest sex differences in the expression and severity of symptoms across both SCI and RRB domains, however findings are mixed (Chawarska et al., 2016; Corbett et al., 2020; Kaat et al., 2020; Mahendiran et al., 2019).

Given, the heterogeneity in symptom presentation, a multi-modal and multi-informant screening and diagnostic assessment process has been recommended in ASD (Chen et al., 2019; Dow et al., 2019; Fedotchev et al., 2019; Jonsdottir et al., 2020). Predominantly, behaviourally based measures administered by clinicians or completed by caregivers and teachers are used. For example, informant-based screening measures such as the Modified Checklist for Autism in Toddlers (M-CHAT) and the Childhood Autism Rating Scale – Second Edition (CARS-2) are common in health care and research settings (Levy et al., 2020; Thabtah & Peebles, 2019). As a diagnostic measure, the clinician-administered Autism Diagnostic Observation Schedule – Second Edition (ADOS-2; Lord C., 2012) is considered a gold standard both for clinical and research purposes (Kamp-Becker et al., 2018). The ADOS-2 encapsulates both domains of an ASD diagnosis. Social communication and interaction symptoms are reflected in the Social Affect (SA) domain and repetitive and restricted behaviours are reflected through the RRB domain (Lord C., 2012). Importantly, characteristics of social attention such as eye gaze, are captured in the scoring of the SA domain, reflecting its importance in the assessment of SCI in ASD (Lord C., 2012).

More recently however, our improved understanding of genetic aetiologies, neurocognitive and neurophysiological markers have prompted researchers to investigate the accuracy of other modes of measurement. Assessment techniques including genetic testing (Genovese & Butler, 2020), functional Magnetic Resonance Imaging (fMRI; Lau et al., 2019), eye tracking (Frazier et al., 2016), and electroencephalography (EEG; Thapaliya et al., 2019) provide objective approaches to assessing ASD beyond the more subjective methods associated with traditional, clinician- or informant-based questionnaires. Furthermore, technological advancements in recent years, have facilitated the development and testing of novel methods using artificial intelligence (AI), machine learning, and advanced computational approaches (Chen et al., 2020; Fedotchev et al., 2019; Guillon et al., 2019; Ray et al., 2019; Shahamiri & Thabtah, 2020; Stevens et al., 2019). Altogether, the clinical and research field is moving towards a holistic and multi-dimensional assessment approach to complement the highly heterogenous nature of ASD and achieve more accurate, cost-effective, and earlier screening and diagnostic outcomes.

1.3. Comorbidities and Co-occurring Conditions in ASD

In addition to its phenotypic heterogeneity, the prevalence of comorbidities and co-occurring conditions contribute to the overall clinical heterogeneity in ASD (Masi et al., 2017). It has been estimated that approximately 70% of autistic children have one comorbidity, and 40% have two or more comorbidities, most commonly intellectual and language impairments (American Psychiatric Association, 2022). A breadth of other neuropsychiatric and mental health conditions, executive function impairments, and emotional and behavioral regulation challenges, co-occur more frequently than in the general population (Demetriou et al., 2017; Lai et al., 2019; Mandy et al., 2022; Mosner et al., 2019; Samson et al., 2014). Neuropsychiatric conditions such as attention deficit hyperactivity disorder (ADHD) and anxiety disorders are highly prevalent with overlapping symptom profiles (Antshel & Russo, 2019; Lawson et al., 2015; Shephard et al., 2019; Spain et al., 2018). These factors may be directly relevant to social attention, as some research suggests that discrepancies in the development of social attention mechanisms may be involved in the development of both ADHD and ASD (Braithwaite et al., 2020; Gui et al., 2020). In line with this, evidence suggests that the co-occurrence of these conditions leads to poor social and adaptive functioning outcomes for these individuals (Liu et al., 2021; Spain et al., 2018; Zachor & Ben-Itzchak, 2019).

Impairments in intellectual functioning, which is often subdivided into verbal IQ (VIQ) and non-verbal IQ (NVIQ) composites, have previously been put forth as a contributor to a distinct endophenotype in ASD (Ankenman et al., 2014; Bishop et al., 2011; Nowell et al., 2017). Epidemiological research estimates co-occurrence rates ranging from 30-70% (Charman et al., 2011; Fombonne, 2005; Howlin, 2006). Consistent with the reported heterogeneity in diagnostic symptoms, research has highlighted the heterogeneity in intellectual functioning in children with ASD, across both NVIQ and VIQ, with no clear pattern in findings (Howlin, 2006). There is however evidence associating NVIQ and VIQ with social communication skills overall (Black et al., 2009), and social attention more specifically (Chawarska et al., 2012; Plesa Skwerer et al., 2019).

In addition, research has shown that delays in receptive and expressive language skills, which comprise VIQ, are prevalent in autistic children (Kwok et al., 2015; Plesa Skwerer et al., 2019; Tager-Flusberg et al., 2005). Discrepancies in receptive language skills have been demonstrated between high and low-risk infants as young as 17 months of age (Hauschild et al., 2022). Indeed, regressions in vocalisations or expressive language are often what first alerts parents of a developmental concern with their child (McDaniel et al., 2018; Tager-Flusberg et al., 2005). In autistic children, impairments in both expressive and receptive language skills have been shown across childhood (Kwok, 2015). Additionally, recent findings indicate that reduced social responsiveness in earlier years may be predictive of language skills in later years in this population (Su et al., 2021; Taylor et al., 2020). Relatedly, delays in literacy skills such as phonological processing, reading, and comprehension have also been reported in autistic children (Arciuli & Bailey, 2021; Jokel et al., 2020; Nally et al., 2018; Westerveld et al., 2016). In some of these studies, poorer literacy skills have been associated with greater autism severity (Nally et al., 2018), and poorer intellectual and adaptive functioning (Arciuli et al., 2013; Westerveld et al., 2016).

1.4. Social Attention, Joint Attention, and Social Cognition

In the literature, social attention is conceptualized through related, although varying perspectives. First, as a visual attention process, social attention relates primarily to social stimuli, such as the face and eyes (Langton et al., 2000; Salley & Colombo, 2016; Tsang et al., 2019). Research has often investigated the differences between, or influence of non-social stimuli on social attention, given that both types naturally occur in our environment (Salley & Colombo, 2016). In autism research involving children, the influence of non-social stimuli has been further subdivided into objects of circumscribed interest (CIs; e.g., trains, mechanical objects) or non-circumscribed interest (e.g., household items, plants) (Sasson et al., 2011; Sasson & Touchstone, 2014; Silver et al., 2020). This categorisation of non-social objects has its origins in Kanner's original findings (1943) as well as later research suggesting that CIs form part of the behavioural RRB repertoire characteristic of ASD (South et al., 2005; Turner-Brown et al., 2011).

A significant body of research has investigated how visual attention processes to social as well as non-social stimuli differ between autistic and non-autistic children (Bellocchi et al., 2017; Chita-Tegmark, 2016b; Clifford & Palmer, 2018; Drysdale et al., 2018; Frazier et al., 2017). Overall, findings do support a divergence, with autistic children exhibiting reduced attention to social stimuli compared to their non-autistic peers (Chita-Tegmark, 2016a, 2016b; Frazier et al., 2017; Nayar et al., 2022). However, the field has been marked by issues in replicability and inconsistencies in findings across heterogenous experimental designs, with studies reporting reduced, similar as well as greater attention to social as well as non-social stimuli compared to neurotypical children (Amestoy et al., 2021; Bottini, 2018; Frazier et al., 2017; Griffin & Scherf, 2020; Mastergeorge et al., 2020; Mouga et al., 2021; Parsons et al., 2017). These issues have underscored the complexity in generating a clear understanding of how these patterns of findings can be applied clinically (Frye et al., 2019; Klin, 2018; Mastergeorge et al., 2020; Tiede & Walton, 2020)

Second, social attention is conceptualized as a component of the broader construct of social cognition, that is, the information processing mechanisms hypothesised to underlie our motivation to attend, understand and interact with others (Frischen et al., 2007; Frith, 2008; Itier & Batty, 2009; Mundy et al., 2007). This perspective may originate from behavioural stimulus-response theories in the sense that behaviours related to self and others (i.e., social behaviour) is a response to the complex neurocognitive processes that are engaged to attend to, understand and act on the social cues (i.e., the stimulus) in one’s environment (Fernandez et al., 2018; Frith, 2008; Happé et al., 2017). These complex cognitive processes are supported by an intricate social brain network integrating dynamic environmental cues and internal responses in adaptive way to produce social behaviours (Fernandez et al., 2018). In ASD, the functioning of this network is believed to diverge from neurotypical individuals, resulting in aberrant social-cognitive processes proposed to underlie the deviations in social responsiveness first described by Leo Kanner (1943), and the SCI challenges characterising our current understanding of ASD (Chevallier et al., 2012; Fernandez et al., 2018; Itier & Batty, 2009; Mundy, 2009; Mundy, 2018; Weston, 2019).

Within the construct of social cognition, social attention is intimately related to joint attention (Mundy et al., 2007; Mundy & Burnette, 2005; Salley & Colombo, 2016). Joint attention is a triadic socio-cognitive process involving the shared awareness of another's gaze in reference to a spatially removed object (Mundy, 2018; Mundy et al., 2009). Within this process, other socio-cognitive constructs including face processing, emotion recognition, and the recognition of the intentional actions of others (that is, action recognition) are jointly engaged in a goal-directed behaviour regarding the target object of interest (Mundy, 2018; Mundy et al., 2009). In addition, other communicative cues such as verbalisations and gestures are also typically involved (Braddock & Brady, 2016; Mundy, 2018; Zimmer, 2015). Joint attention processes have been shown to emerge from around 6 months of age, and there is a significant body of research supporting the difficulties some autistic children exhibit with this complicated social behaviour (Dawson et al., 2004; Korhonen et al., 2014; Mundy, 2018; Nystrom et al., 2019). Importantly, joint attention is considered a developmental precursor to other higher-order social-cognition constructs such as theory of mind (ToM, mentalizing abilities), in addition to language and SCI skills (Bedford et al., 2012; Bottema-Beutel et al., 2019; Gulsrud et al., 2014; Kristen et al., 2011; Mundy, 2009; Mundy & Jarrold, 2010; Poon et al., 2012; Swanson & Siller, 2013).

Social attention has also been interpreted as a marker of social motivation, meaning the intrinsic motivation to orient to social cues in our environment (Chevallier et al., 2012; Salley & Colombo, 2016). Through this interpretation, social attention has been investigated as both a visual attention process and social behaviour rooted in evolutionary, genetic, and neurobiological mechanisms that innately enhance the reward value or saliency of social over non-social cues (Chevallier et al., 2012). This interpretation is also reflected in neurocognitive research suggesting that perceptually driven bottom-up attentional mechanisms involved in the initial orientation to salient, i.e., social stimuli, function atypically in autistic populations (Amso et al., 2014; Shic et al., 2007; Xu et al., 2019). This interpretation has led to its development as a dominant theory in social attention research in ASD, a topic that will be discussed in the next section.

1.5. Prominent Theories of Social Attention in ASD

One of the most prominent theories of social attention in autism research is the social motivation hypothesis. This hypothesis is grounded in the supposition that the biological mechanisms subserving the motivation or reward value of orienting to social cues and interacting with others are impaired in ASD (Chevallier et al., 2012). More specifically, the theory draws on earlier neuroimaging research to suggest that stimulus driven or 'bottom-up' attentional mechanisms, which are thought to be involved in our innate ability to orient to and appraise the saliency of stimuli, such as the faces and eyes of people, is disrupted in ASD (Chevallier et al., 2012; Itti & Koch, 2000; Kennedy & Adolphs, 2010; Mundy & Bullen, 2022). In turn, these disrupted biological mechanisms are posited to result in the early-age onset of reduced social attention, leading to the cascading developmental effects in social cognition processes and reduced social responsiveness (Chevallier et al., 2012). The hypothesis was considered to diverge from earlier cognitive accounts of diminished social attention, such as weak central coherence theory, which suggested that autistic individuals were biased towards detail oriented processing over more integrated, global processing mechanisms, as employed in face processing (Chevallier et al., 2012; Happé, 2005; López et al., 2004). Contrary to these earlier cognitive theories, the social motivation hypothesis considered the socio-cognitive characteristics of ASD as behavioural sequalae to, rather than causes of, atypical social attention patterns (Chevallier et al., 2012).

The social motivation hypothesis has received mixed support over the years. The theory has received some support from neuroimaging studies evidencing atypical activation of neural circuitry associated with reward processing in experimental tasks involving social stimuli (Kinard et al., 2020; Kohls et al., 2018). Additional support for the theory's proposition of an innate and biological original to social attention has emanated from genetic research demonstrating reduced eye-to-eye contact in monozygotic twins (Constantino et al., 2017), and behavioural studies conducted in the first few months of life in which infants at high risk for ASD exhibit atypical gaze to the eyes and faces of others (Bradshaw et al., 2019; Chawarska et al., 2013; Di Giorgio et al., 2021; Jones & Klin, 2013). Furthermore, a number of behavioural studies have also demonstrated associations between reduced social attention and compromised developmental outcomes including ToM and SCI skills in autistic populations (Bedford et al., 2012; Brooks & Meltzoff, 2015; Chawarska et al., 2013; Klin et al., 2002; Tang et al., 2017; Tsang, 2018). These findings could be argued to be supportive of the developmental sequelae posited by the theory.

However, the theory's conceptual framework has been challenged in different ways. For example, there is accumulating evidence to suggest that autistic individuals experience attentional perturbations across social and non-social domains (Bedford et al., 2014; Bottini, 2018; Clements et al., 2018; Keehn et al., 2017). Indeed, findings from a growing body of neuroimaging and neurophysiological research suggests a broader pattern of hypoactivation of reward, attention and arousal networks in response to both social and non-social salient stimuli (Bast et al., 2018; Dichter et al., 2010; Keehn et al., 2017; Richey et al., 2014). Concurrently, neuroimaging and eye-tracking research has suggested increased salience network activity and attention, respectively, in response to non-social stimuli related to circumscribed interests (CIs) (Clements et al., 2018; Kohls et al., 2018). Outcomes from earlier eye-tracking studies investigating attention patterns to social and non-social stimuli inclusive of CI and non-CI stimuli led some researchers to propose that it may be the presence of CIs that influence social attention patterns in ASD rather than attention to social stimuli *per se* (Sasson et al., 2011; Sasson & Touchstone, 2014; Sasson et al., 2008). However, more recent eye-tracking studies employing similar experimental paradigms have produced equivocal results (Gale et al., 2019; Harrison & Slane, 2020; Silver et al., 2020; Unruh et al., 2016), highlighting the need for replication and additional investigation in the influence of CI's on social attention patterns in ASD . Taken together, the results across research modalities suggest that dysfunctional neural circuits of both hyper- and hypo- attentional mechanisms may underlie the atypical attention patterns across social and non-social domains reported across the research field (Bottini, 2018; Clements et al., 2018; Cuve et al., 2018; Frazier et al., 2017; Keehn et al., 2017).

Moreover, the theory implicitly projects a uni-directional approach to social attention, for example, by suggesting that bottom-up processing mechanisms drive the attribution of social cues as salient and therefore the intrinsic motivation or reward value of orienting to these cues (Chevallier et al., 2012; Mundy & Bullen, 2022). There has been less consideration of how top-down attentional mechanisms, involving higher order cognitive networks capturing goal-directed behaviour and semantic knowledge, influence saliency attribution (Bottini, 2018; Jure, 2019;

Katsuki & Constantinidis, 2014), nor of the interplay between bottom-up and top-down mechanisms in guiding visual and social orientation across typical and ASD populations (Amso et al., 2014; Connor et al., 2004; Mundy & Bullen, 2022). In addition, other studies have not found significant associations between social attention and ToM (Burnside et al., 2017), or the hypothesised predictive effects of social cognition on social responsiveness (Morrison et al., 2020). Taken together, these results undermine the theory's proposed framework suggesting that reduced social attention impairs social cognitive development and social responsiveness in ASD.

Recently, an alternative conceptual model has been proposed. The social brain hypothesis considers the interrelationships between social attention, social cognition, and social interaction in ASD (Mundy, 2018). This theory originates from comparative research and provides an evolutionary perspective on the relationship between the size of the brain and the size and complexity of social groups and mating rituals, respectively, in highly evolved species such as humans and primates (Dunbar, 2009). Extrapolating this notion to human social cognition and behaviour, the theory would suggest that natural selection processes drive the evolution and complexity of social cognition constructs in adapting to the demands of social environments (Dunbar, 2009; Mundy, 2018). The theory builds upon the genetic and neural basis of social attention posited by the social motivation hypothesis (Chevallier et al., 2012; Constantino et al., 2017; Isaksson et al., 2019; Misra, 2014) , by emphasizing the interpersonal and bi-directional effects of social behaviours such as eye gaze on brain development (Grossmann & Johnson, 2007; Kennedy & Adolphs, 2012; Nummenmaa & Calder, 2009). Potentially, the theory could be further developed by integrating recent investigations in the neural basis of parent-child and social interactions (Kuboshita et al., 2020; Nguyen et al., 2020; Turk et al., 2022; Ulmer-Yaniv et al., 2022), and how these may relate to social responsiveness and adaptive functioning in ASD specifically.

Over the years, researchers have proposed alternative explanations for some of the characteristic behaviours exhibited by autistic individuals, including atypical visual attention patterns. One such theory explains these behaviours as a deficit in predictive coding. The predictive coding theory in ASD suggests that a lack of adaptability to learn from errors in prediction, and antecedent stimulus-response or event-outcome associations, may underlie many of the behaviours considered characteristic of ASD (Pellicano & Burr, 2012; Sinha et al., 2014; Van de Cruys et al., 2014). For example, it has been suggested autistic children's perseverative attention to CIs, may be a consequence of a deficit in predictive coding whereby their ability to automatically predict that a shift in attention is required as task stimuli changes is impaired (Sasson & Touchstone, 2014; Van de Cruys et al., 2014). In another study investigating this theory more directly, it was reported that compared to their neurotypical peers, autistic adolescents were less likely to direct their gaze in response to a learned association between a cue and the location of either social or non-social stimuli, which the researchers interpreted as evidence for a deficit in predictive coding (Greene et al., 2019).

The notion of an impaired predictive coding mechanism has been suggested to extend across both SCI and RRB domains of ASD (Sapey-Triomphe et al., 2019; Van de Cruys et al., 2014; van Laarhoven et al., 2019). In relation to the SCI domain, impaired predictive coding has been theorised to lead to a developmental impairment in anticipating prosocial behaviour in group settings (Hepach et al., 2020). While in the RRB domain, an 'insistence of sameness' and engagement in repetitive behaviours has been viewed as an heightened effort to establish a sense of regularity and control in anticipated outcomes in an unpredictable world (Sinha et al., 2014;

Van de Cruys et al., 2014). Nevertheless, support for the predictive coding theory has also been inconsistent, with recent reviews reporting mixed results and methodological limitations in an acknowledged heterogenous research field (Angeletos Chrysaitis & Seriès, 2023; Cannon et al., 2021). While other theories may provide additional perspectives, broadly speaking, no particular theory has been able to adequately explain the variability in social and non-social attention patterns observed across neurologically or behaviourally based studies, or of the underlying mechanisms driving 'bottom-up' or 'top-down' attentional processes, indicating the need to develop greater conceptual clarity of social attention and its developmental relevance in ASD (Falck-Ytter et al., 2023).

1.6. Measurement of Social Attention in ASD

1.6.1. Use of Eye Tracking Methodologies

While a variety of experimental methods have been used to measure social attention in autistic children, the past two decades has witnessed the increasing popularity of eye-tracking methods (Horsley et al., 2014; Vehlen et al., 2021). Eye tracking is as a non-invasive, objective, and relatively simple method of capturing and measuring the eye movements of individuals (Carter & Luke, 2020). Most modern eye trackers use infrared technology to measure where an individual is fixating their gaze based on calculations of visual angles between pupil and corneal light reflections captured on camera, termed the pupil-corneal reflection (P-CR) method (Holmqvist et al., 2022). One of the significant advantages of eye tracking is that the behavioural and cognitive demands of the tasks developed can be tightly controlled, ranging from passive viewing to more interactive requirements (Carter & Luke, 2020; Venker et al., 2019). This makes it particularly suitable for studying social attention from infancy and throughout development. These features also complement research in ASD, a clinical population characterised by its heterogeneity in symptomatology and co-occurring conditions (Hawks & Constantino, 2019; Rosello et al., 2021; Venker et al., 2019).

In autistic children, past studies have applied a myriad of different eye tracking tasks and outcome measures to examine social and non-social attention differences, most typically against neurotypical populations (Chita-Tegmark, 2016b; Frazier et al., 2021a; Hamner & Vivanti, 2019; Mastergeorge et al., 2020; Nayar et al., 2022). By defining areas of interest (AOIs) around stimuli to be tested, various measures are calculated to highlight nuances in social attention patterns and potential underlying socio-cognitive mechanisms. For instance, variables such as time to first fixation and first fixation duration are commonly calculated as an index of reflexive orienting or the prioritisation of attention to social cues, suggestive of early social information processing and bottom-up cognitive mechanisms (Carter & Luke, 2020; Itier & Batty, 2009; Sasson & Touchstone, 2014). Other temporal variables such as fixation duration and frequency measure how long and often, respectively, participants fixate on different AOIs over the course of the task and are considered indicative of later information processing (Carter & Luke, 2020); however, depending on the duration and demands of the task, may be reflective of both bottom-up and top-down mechanisms.

In general, eye-tracking methods can be grouped according to whether the task is static (i.e., a picture with no moving elements); dynamic (i.e., there are moving elements, for example, in a movie or video); or interactive, using recent technological advancements in wearable eye-tracking glasses or via online video streaming (Meißner et al., 2019). To date, static and dynamic tasks, requiring little more than passive viewing, dominate the literature in autism research (Chita-Tegmark, 2016b; Frazier et al., 2017; Riddiford et al., 2022). There have been some studies employing interactive eye-tracking techniques in this population, with variable success rates

(Birmingham et al., 2017; Edmunds et al., 2017; Nag et al., 2020). Atypical sensory processing characteristics (Griffin et al., 2022), and concerns regarding the potential influence of wearable eye-trackers in the naturalism of social interactions (Meißner et al., 2019), suggest that other interactive techniques may be more appropriate in young autistic children.

1.6.2. Use of Eye Tracking in Static and Dynamic Contexts

Historically, due to the highly controlled, purely cognitive approach to social attention research, static tasks were primarily used in autistic children, with variable effects reported (Chevallier et al., 2015; Hanley et al., 2014; Sasson et al., 2008). Importantly, research utilising static tasks has been able to identify discreet mechanisms influencing the hypothesised innate bias, or lack thereof, to social cues. For example, earlier research investigating the influence of CIs in young autistic children suggested that a bias to CIs resulted in the reduced social attention patterns observed in comparison to their neurotypical peers, rather than the global reductions in social attention posited by the social motivation hypothesis (Elison et al., 2012; Sasson & Touchstone, 2014). However, more recent research on the influence of CIs suggests atypicalities across both social and non-social domains and a moderating influence of CIs for both neurotypical and autistic children, supporting domain general attention models (Keehn et al., 2016; Unruh et al., 2016).

Studies utilising static contexts to investigate social attention patterns across other types of conditions have similarly produced mixed findings. These studies including conditions comparing direct or averted gaze (Akechi et al., 2010; Senju et al., 2008), variability across different facial expressions (de Wit et al., 2008; Su et al., 2019) or other social cues like the mouth (Gillespie-Smith et al., 2014; G. Wang et al., 2018). There are some researchers who argue that these types of inconsistencies are attributable to the characteristics or demands of the task

(Chevallier et al., 2015; Drysdale et al., 2018). Nevertheless, there are broader concerns that these types of static tasks lack the richness and complexity of cues found in natural environments, thereby encouraging researchers to investigate social attention through dynamic paradigms (Chevallier et al., 2015; Greene et al., 2020; Kaliukhovich et al., 2021; Shaffer et al., 2017).

Dynamic contexts in eye tracking have primarily been designed to embed some degree of ecological validity whilst maintaining elements of experimental control (Großekathöfer et al., 2021). For example, video clips from popular movies, as well as experimentally designed tasks have been used to examine social and joint attention behaviours. In the landmark study by Klin et al. (2002), autistic and neurotypical adolescents viewed a clip from the 1967 movie "Who's afraid of Virginia Woolf", with the authors reporting reduced attention to the eyes of interacting actors and greater attention to background objects in autistic participants (Klin et al., 2002). These social and non-social attention patterns were found to be related to greater symptom severity and poorer socialisation skills, respectively (Klin et al., 2002).

However, subsequent research including dynamic, experimentally designed eye-tracking tasks have produced equivocal findings. Chawarska and colleagues developed a dynamic task involving a presenter engaging in a series of activities against a background of toys to explore factors underlying the social attention patterns observed in autistic toddlers (Chawarska et al., 2012). The results of this highly cited study found that in comparison to neurotypical toddlers, autistic toddlers only exhibited reduced attention to the face in conditions involving bids for joint attention or dyadic interaction, and not in other conditions where bids for direct engagement were not present (Chawarska et al., 2012). Overall, there were no reported associations between attention to the face and socialisation skills or autism severity, although the dyadic condition garnered some indications of associations between attention to the scene and cognitive functioning (Chawarska et al., 2012). A more recent study comparing autistic and neurotypical toddlers, involving a similar context of an actor speaking directly to the viewer with a background of distractor stimuli, found the opposite pattern; autistic children exhibited reduced attention to the eyes in the passive viewing condition, not the explicit cueing condition (Moriuchi et al., 2017). In that study, however, associations with clinical characteristics or broader functioning measures were not examined.

Dynamic eye tracking tasks have also been used to investigate the mechanisms underlying joint attention. Objectively, these tasks are often designed to only examine components of joint attention such as gaze cueing or following behaviours (Cilia et al., 2019; Franchini et al., 2017; Grynszpan et al., 2019; Wang et al., 2020). They rarely encapsulate the temporal social attention process inherent in generating the shared awareness and goal directed elements that define this key social communication skill (Mundy et al., 2007). In addition, joint attention tasks often lack ecological validity (Kwon et al., 2019; Muratori et al., 2019; Wang et al., 2020), developmental relevance (Ishizaki et al., 2021), and have been argued to be unrepresentative of the natural types of interactions experienced between children and caregivers (Justice et al., 2008; Justice et al., 2006). Taken together, these findings highlight that even across dynamic paradigms, challenges in developing ecologically relevant paradigms and inconsistencies in findings exist, thus prompting researchers to adopt more realistic contexts in social attention research (Nyström et al., 2019; Palomo et al., 2022; Wicks et al., 2022).

1.6.3. Understanding the Influence of Social Interactions in Live Contexts

In neurotypical populations, research supports the notion of a natural variability of gaze across social contexts (De Haas et al., 2019; Foulsham, 2020; Foulsham & Kingstone, 2017; Strukelj et al., 2016). Potentially due to learned experience of social norms, social gaze behaviours have been found to vary between screen-based tasks and live interaction settings involving actual or anticipated social interactions (Foulsham & Kingstone, 2017; Gregory & Antolin, 2019; Holleman et al., 2020). This natural variability in gaze across social contexts has also been supported in physiological studies examining oculomotor control (Strukelj et al., 2016). Considering that social contexts including live interactions may be most representative of real-life settings, and therefore of greatest ecological relevance, understanding how social interactions in live contexts influence social attention is important (Cole et al., 2016; Risko et al., 2012; Risko et al., 2016).

In ASD, only recently have researchers considered how contexts involving social interactions may influence social attention patterns. To date, most studies involving social interactions in autistic populations have investigated differences in social attention with neurotypical individuals. Both in studies involving adults or children with ASD, findings have been mixed. Some studies have reported reduced social attention (Auyeung et al., 2015; Noris et al., 2012) while others have found reductions in one condition but not another (Falck-Ytter, 2015; Jones et al., 2017; Thorup et al., 2016), or no significant group differences (Cañigueral & Hamilton, 2019; Grossman et al., 2019). These patterns of findings appear to mimic the evidence across static and dynamic contexts. Nevertheless, they are not informative of how social attention in one context may relate to another context, underscoring the gap in our understanding of the variability in social attention across social contexts in autistic populations.

Research investigating how social attention may differ across static, dynamic, and interactive contexts in ASD is scarce, and unsurprisingly, inconsistent findings have also emerged (Chevallier et al., 2015; Grossman et al., 2019; von dem Hagen & Bright, 2017). Nevertheless, there are broader indications that social contexts involving social interactions may impart a variable influence in the social attention patterns of autistic children (Chawarska et al., 2012; Chita-Tegmark, 2016b; Frazier et al., 2017). Furthermore, recent evidence suggests that these differences may extend to general measures of social functioning (Riddiford et al., 2022). However, the lack of within group comparisons comparing social attention across these different contexts, particularly in young autistic children, represents an important gap in the literature that needs to be addressed.

1.7. The Relationship Between Social Attention, Autism Severity, Cognitive Skills, and Social Functioning

There is an accumulating body of research indicating that social attention is associated with the severity of autism symptoms and social and adaptive functioning more broadly (Riddiford et al., 2022; Shic et al., 2022; Tillmann et al., 2019; van Rijn et al., 2019). In infants, some research reports that reduced social attention is associated with a greater severity of symptoms and poorer social functioning during toddlerhood (Jones & Klin, 2013; Thorup et al., 2016; Tsang et al., 2019). While conflicting findings exist (Jones et al., 2017; Parsons et al., 2019), these associations have been supported throughout childhood, with a recent meta-analysis reporting small and medium effect sizes in the association between autism severity/social functioning and attention to the eyes and face, respectively (Riddiford et al., 2022).

Similarly, a growing body of evidence suggests that joint attention skills are also related to clinical characteristics and social functioning (Bottema-Beutel et al., 2019; Pickard & Ingersoll, 2014; Poon et al., 2012; Taylor et al., 2020). Recently, a large study ($N = 249$) in autistic young children reported that scores on a battery of social communication measures including joint attention, were related to the severity of autism symptoms (Taylor et al., 2020). In another meta-analytic review, small to medium effect sizes were reported for the association between joint attention and social functioning (Bottema-Beutel et al., 2019). There is also some evidence suggesting an association between joint attention and cognitive functioning more broadly (Poon et al., 2012; Zaidman-Zait et al., 2020).

However, the most robust associations are between joint attention and language skills (Braddock & Brady, 2016; Mundy et al., 1990; Pickard & Ingersoll, 2014; Tomasello & Farrar, 1986; Walton & Ingersoll, 2013). This association has been demonstrated in infants, where the ability to learn words related to objects was predicted by the redirection of gaze from the person verbalizing the word to the labelled object (Itier & Batty, 2009). In infants at high risk for ASD, there is also some research to suggest that atypical gaze between people and objects may be related to word knowledge (Parsons et al., 2019; Walton & Ingersoll, 2013). Evidence of the associations between joint attention and language development have been reported across childhood in ASD, even when controlling for potentially moderating factors such as age, language level and IQ (Mundy et al., 1990; Pickard & Ingersoll, 2014; Plesa Skwerer et al., 2019). The collective evidence base linking joint attention to language and other developmental outcomes has spurred the development of different interventions to mitigate these effects in this population (Murza et al., 2016; Stavropoulos & Carver, 2013).

In summary, there is a substantial body of behavioral research demonstrating atypical social and joint attention behaviours in autistic children compared to their neurotypical peers. Researchers have proposed that social attention may be a unique social endophenotype in ASD (Braithwaite et al., 2020; Tiede & Walton, 2020), and evidence from neuroimaging (Li et al., 2020; Paul et al., 2021), neurophysiological (Bast et al., 2018; Isaev et al., 2020) and genetic (Constantino et al., 2017) studies lend further support for this contention. Overall, these findings have instigated research in developing social attention, and in particular eye tracking, as a biomarker for screening, diagnostic and intervention purposes (Frazier et al., 2016; Frye et al., 2019; Murias et al., 2018; Shic et al., 2022; Wen et al., 2022).

However, the the body of research has been marked by mixed findings across experimental contexts (Del Bianco et al., 2020; Mastergeorge et al., 2020). Concerns regarding the ecological validity of tasks and the generalisation of findings to real life settings have also been raised (Cole et al., 2016; Hamner & Vivanti, 2019; Risko et al., 2012). In turn, these factors have undermined established conceptual frameworks and hampered research translation efforts for clinical applications (Klin, 2018). Potentially, by adopting a cross-contextual approach to the measurement of social attention and examining its associations with autism symptomatology and social functioning more broadly, this may enhance our conceptual understanding of social attention and guide a more effective approach to its development as a biomarker for diagnostic and treatment outcome purposes in children with ASD.

1.8. Research Aims

The overall objective of this research project was to investigate cross-contextual patterns of social attention in a young cohort of autistic children. To meet this objective, the first aim of the project was to investigate patterns of social attention in this young autistic cohort compared to an age-matched neurotypical cohort using a static eye-tracking context. Considering the importance of differentiating attention to social versus non-social stimuli, and previously raised concerns regarding task heterogeneity and mixed findings in this field of research, an established, visual preference eye tracking task was chosen to investigate these social attention patterns.

The second aim of this project was to develop and validate a novel, ecologically and developmentally relevant, dynamic eye-tracking task for the investigation of patterns of social and joint attention in autistic and neurotypical children. The third aim of this project was to explore the relationship in social attention patterns between a social context involving a play-based social interaction between a researcher and the autistic child, and the eye tracking tasks used in this thesis. This component of the thesis was only investigated in the autistic cohort. Finally, the project sought to explore how the social attention patterns across each context related to autism symptomatology, cognitive skills, and social functioning more broadly.

1.9. Hypotheses

In consideration of the reviewed literature described above, three core hypotheses were made and tested. It was hypothesised that children with ASD would exhibit:

- Patterns of reduced social attention across static and dynamic contexts, compared to their neurotypical peers.
- Reduced joint attention behaviours in the dynamic context, compared to their neurotypical peers.
- Differences in social attention patterns across static, dynamic, and live interaction contexts.

It was also hypothesised that in the autistic cohort, there would be some evidence associating reduced social attention with greater autism severity or reduced social functioning, however the limited research examining these associations within these different social contexts prevented a more specific hypothesis being made. Similarly, limited research precluded any hypotheses being made regarding associations between social attention and cognitive skills in young autistic children.

1.10. Research Program

To address the main objectives of this research project, investigating how patterns of social attention present across different social contexts, and exploring their relationship with clinical characteristics, this thesis is divided into three interrelated internal chapters. These chapters address issues such as the variability in social and non-social attention, the influence of social context, and the ecologically validity of research methods, which are important objectives in this field of research.

In Chapter 2, the social and non-social attention patterns of autistic children and their neurotypical peers in a static eye-tracking context are examined. A widely used visual preference task was employed, in which the influence of CI objects on social attention was investigated. The associations between these attention patterns with ASD severity and social functioning were explored and discussed.

In Chapter 3, the development of a novel, ecologically and developmentally relevant dynamic task, based on a shared book reading scenario, is described. The chapter reports on whether the task discriminates social and non-social attention patterns, and joint attention behaviours between autistic children and their neurotypical peers. The chapter also described how these attentional patterns relate to autism severity, cognitive skills, including non-verbal IQ and receptive language skills, and social functioning.

In chapter 4, the relationships in social attention in the autistic cohort is examined across three different contexts: 1) the static eye-tracking task (as described in chapter 2), 2) the dynamic eye tracking task (as described in chapter 3), and 3) a play-based social interaction task (‘free play’) between autistic children and a researcher. The associations between social attention and autism severity and social functioning within each context are reported.

In the fifth and final chapter, a general discussion and synthesis of the findings, their contributions, and how they relate to conceptual and clinical developments in the field are discussed. This is followed by a discussion on the limitations of the project and opportunities for future research.

2. Evidence of a Reduced Role for Circumscribed Interests in the Social Attention Patterns of Children with Autism Spectrum Disorder

Preface

As introduced in Chapter 1, the field of social attention research in ASD is marked with mixed findings. Mixed findings are observed across different experimental tasks and contexts, as well as across studies utilising similar or established tasks. As exemplified in Chapter 1, studies investigating the effects of CIs on social attention patterns in smaller cohorts of autistic children have demonstrated such inconsistencies, creating a need to conduct further research in broader age and larger cohorts of autistic children. In conjunction, variable influences of task characteristics or demands on social attention has led researchers to suggest that more replication studies are needed. Thus, in Chapter 2, a traditional, static visual preference task using similar outcomes measures to previous studies is employed. The purpose of this was to develop the field's understanding of how CIs may differentially impact attention to both social and non-social stimuli in autistic and neurotypical pre-adolescent children.

Abstract

Reduced social attention is characteristic of autism spectrum disorder (ASD). It has been suggested to result from an early onset and excessive influence of circumscribed interests (CIs) on gaze behaviour, compared to typically developing (TYP) individuals. To date these findings have been mixed. The current eye-tracking study utilised a visual preference paradigm to investigate the influence of CI versus non-CI objects on attention patterns in children with ASD (aged 3-12 years, n = 37) and their age-matched TYP peers (n = 30). Compared to TYP, social and object attention was reduced in the ASD group irrespective of the presence of CIs. Results suggest a reduced role for CIs and extend recent evidence of atypical attention patterns across social and non-social domains in ASD.

2.1. Introduction

Atypicalities in attention to social information is central to diagnostic criteria for autism spectrum disorder (ASD). The early-age onset and potential cascading effects on social communication and functioning skills has led to a proliferation of research investigating gaze behaviour as a biomarker for early diagnosis and as a potential target for intervention (Bradshaw et al., 2019; Frye et al., 2019; Guastella et al., 2008; Shic, 2016; Webb et al., 2020). Research utilising eye tracking technology has revealed reduced social attention across a range of gaze behaviours, such as the duration of fixations to the eyes and face (Frazier et al., 2017; Klin et al., 2002), the processing of faces and emotional expressions (Black et al., 2017; Dawson et al., 2005), the exploration of, and disengagement from, social stimuli (Chawarska et al., 2010; Sasson et al., 2008), orienting to gaze and gaze following (Senju, 2004; Gillespie-Lynch, 2013), joint attention (Franchini et al., 2017), and social cueing (Chevallier et al., 2013). Reduced attention to social cues has been demonstrated in infants as young as six months of age (Chawarska et al., 2013), across childhood and also throughout adulthood (Chita-Tegmark, 2016b; Frazier et al., 2017). Moreover, there has been growing speculation that reduced attention may contribute to the observed difficulties in social and adaptive functioning (Klin et al., 2002; Poon et al., 2012; Rice et al., 2012; Tang et al., 2017).

There has, however, been much debate about the extent to which differences in social attention are moderated by context and their specificity to social cues. For example, circumscribed interests (CIs), considered to be a factor in the characteristic restrictive and repetitive behaviour profile in ASD (South et al., 2005; Turner-Brown et al., 2011), have been reported to induce biases in visual attention patterns across childhood in ASD (Elison et al., 2012; Sasson et al., 2011; Sasson & Touchstone, 2014). Sasson and Touchstone (2014) investigated the influence of objects of circumscribed or High Autism Interest (HAI; for example, transportation vehicles, mechanical instruments) and Low Autism Interest (LAI; for example, household items, plants) on social attention patterns in thirty young children with and without ASD. They developed a visual preference task involving a series of 20 images of a face paired with either a HAI or LAI object and found that compared to typically developing (TYP) children, children with ASD were slower to orient to and maintain attention to faces when they were paired with HAI objects, however there were no group differences in social attention in the presence of LAI objects. The ASD group in this study also exhibited a greater preference to attend to HAI relative to LAI objects, complementing findings from earlier studies demonstrating an early-onset and discrete preference in children with ASD to explore and perseverate their attention on CIs in comparison to their TYP peers (Elison et al., 2012; Sasson et al., 2011). In a follow-up study with 87 school-age children aged 6 to 10 years, reduced social attention in the presence of HAI was also demonstrated, however this finding was specific only for male participants with ASD; the attention patterns of female participants with and without ASD were not significantly different (Harrop et al., 2018b). In addition to potential phenotypic variations across sexes, the results of these studies suggested that CIs may moderate attention patterns to both social and non-social elements of a scene from an early age in life and therefore potentially represent an important characteristic in children with ASD.

Other studies investigating the unique influence of CIs on social attention patterns in children with ASD, however, have led to variable findings. The visual preference task described above was implemented in a study by Unruh et al. (2016) with results indicating that both adolescents with ASD (n = 41) and their TYP (n = 34) peers demonstrated a preference to attend to HAI compared to LAI objects and reduced social attention in the presence of HAI objects.

Furthermore, analysis of between-group differences revealed a preference to look at both object types (HAI and LAI) in the ASD group, while the TYP group preferred to look at faces. A similar finding was reported by Harrison and Slane (2020), with reduced attention to faces in children and adolescents with ASD ($n = 16$) across object types, and interestingly, a variable influence of HAI on social attention in the TYP ($n = 20$) but not the ASD group ($n = 16$). These results are consistent with other eye-tracking studies reporting a similar influence of CIs in ASD and TYP participants, concurrent with reduced social attention in participants with ASD specifically, throughout development (DiCriscio et al., 2016; Mo et al., 2019; Traynor et al., 2019). Findings of reduced social attention in ASD independent of the influence of CIs across childhood lend support to the social motivation hypothesis, which posits an intrinsic, early-onset impairment in the motivation to attend to and engage with socially relevant stimuli, leading to reduced social learning experiences and cascading effects in overall socio-cognitive and social skill development (Chevallier et al., 2012).

Research exploring the relationship between social attention patterns and overall social functioning have led to similarly equivocal findings. There have been some longitudinal studies reporting a relationship between reduced social attention in infancy and poorer language and theory of mind skills in early childhood (Brooks & Meltzoff, 2015; Poon et al., 2012), however other studies in older children with ASD have not yielded significant associations between social attention and social functioning measures (Fujioka et al., 2020; Unruh et al., 2016; van Rijn et al., 2019). Interestingly, the landmark study by Klin and colleagues (2002), as well as Rice et al. (2012) found that greater attention to objects rather than reduced attention to social stimuli, was associated with greater social impairment, while Sasson (2008) reported a positive correlation between exploration of object stimuli and social impairment. The variability in correlational findings between social attention and functioning suggests further exploration inclusive of non-social attention patterns is warranted. Consistent with the social motivation hypothesis, the imbalance of attention to objects over social stimuli has similarly been theorised to lead to fewer social learning experiences and therefore facilitative of the day-to-day social challenges experienced by individuals with ASD (Sasson et al., 2008).

There are equivocal findings across previous studies, suggesting on one hand that the excessive influence of CIs determines the variability in social attention patterns in ASD, and on the other hand, that social attention in this population is reduced irrespective of stimuli and context. This presents a need to better understand how CIs influence the attention patterns of children with ASD and their TYP peers. Thus, the goal of this study was to investigate the influence of CIs on social and object attention patterns in children with ASD compared to TYP peers using established task and outcome measures, and to explore the relationship between these patterns and social functioning. An established visual preference task was employed to facilitate comparability with past research. Based on recent findings, it was hypothesised that a reduction in social attention would be evident in the ASD group regardless of the presence of CIs. It was also hypothesised that both ASD and TYP groups would exhibit greater attention to HAI (i.e., CIs) compared to LAI objects. No hypotheses were made regarding the relationship between attention and social functioning given the variability in findings across studies (Klin et al., 2002; Poon et al., 2012; Rice et al., 2012; Sasson et al., 2008; Unruh et al., 2016; van Rijn et al., 2019).

2.2. Methods

2.2.1. Participants

Participants were 67 children; 37 children diagnosed with ASD and 30 TYP children, aged 3-12 years (ASD: M = 8.06, SD = .40; TYP: M = 7.41, SD = .48). Similar to previous studies (DiCriscio et al., 2016; Harrison & Slane, 2020) a broad age range was selected in consideration of the characteristic persistent influence of CIs and reduced attention allocation to social stimuli throughout development in ASD (Frazier et al., 2017; Manyakov et al., 2018). There was no significant difference in age between groups (t = -1.06, p = .295), however a trend in the distribution of male and female participants was observed, with 66.7% and 89.2% male participants in the TYP and ASD groups, respectively, χ^2 (1, 67) = 3.813, p = .051, phi = .024. Participant characteristics are presented in Table 2.1.

Table 2.1

Participant Characteristics

Characteristic	ASD (*n* = 37)			TYP (*n* = 30)		
Gender						
Male	33			20		
Female	4			10		
	Mean	*SD*	Range	Mean	*SD*	Range
Age in years	8.06	2.42	3 - 12	7.41	2.63	3 - 12
Nonverbal IQ[a]	97.24	14.59	68 - 129	116.04**	12.94	97 - 151
SRS-2 Mean T-Scores[b]						
Total	77.57	9.36	58 – 90	46.32**	7.32	36 – 64
SCI	76.38	9.52	56 – 90	46.04**	7.21	35 – 62
RRB[1]	77.89	9.21	48 – 90	47.79**	9.00	40 – 80
ADOS-2 CSS						
Total	7.51	1.52	5 – 10	-	-	-
SA	7.54	1.83	3 – 10	-	-	-
RRB[2]	7.22	1.89	1 – 10	-	-	-

Note. ASD, autism spectrum disorder; TYP, typically developing; SRS-2, social responsiveness scale – second edition; SCI, social communication and interaction; RRB[1], restricted interests and repetitive behaviours; ADOS-2, autism diagnostic observation schedule – second edition; CSS, calibrated severity score; SA, social affect; RRB[2], repetitive and restricted behaviours.

[a] Nonverbal IQ scores from the Leiter-3 for ASD (*n* = 33) and TYP (*n* = 23). [b] SRS-2 Mean T-Scores for ASD (*n* = 37) and TYP (*n* = 28).

** Indicates a significant group difference at $p < .001$.

Participants were recruited through the Autism Clinic for Translational Research located at the Brain and Mind Centre, within The University of Sydney. Study eligibility of participants with an ASD diagnosis was confirmed using the Autism Diagnostic Observation Schedule -

Second Edition (ADOS-2; (Lord C., 2012), administered by research-reliable assessors. Individuals with severe renal, hepatic, cardiovascular or respiratory illness were excluded from the study. Recruitment of TYP participants occurred through locally distributed flyers and by word-of-mouth. Exclusion criteria for TYP participants included neurodevelopmental or mental health diagnoses (e.g., anxiety, depression, ASD, sensory processing disorder) and severe physical illnesses (e.g., severe cardiac, hepatic, renal, respiratory illness).

Once enrolled, all participants were administered the Leiter-3 (Roid et al., 2013), a nonverbal cognitive assessment, and caregivers completed the Social Responsiveness Scale - Second Edition (SRS-2; (Constantino & Gruber, 2012) as a global measure of social functioning. The research project was approved by the Human Research Ethic Committee (HREC) of The University of Sydney (references 2013/502, 2013/341), and informed consent was obtained from caregivers prior to study enrolment.

2.2.2. Measures

Autism Diagnostic Observation Schedule – Second Edition (ADOS-2; Lord C., 2012)

The ADOS-2 is a semi-structured, play-based observational measure of common autism symptoms, which fall under the broad domains of Social Affect (SA; including communication, social interaction, and play-based behaviours) and Repetitive and Restricted Behaviours (RRB; including unusual sensory interests, aggressive and stereotyped behaviours). Modules 1 (n = 13), 2 (n = 15) or 3 (n = 9) were administered based on participant age and expressive language level. As a standardised measure of core symptom severity, total and domain calibrated severity scores (CSS), ranging from 1 to 10, were calculated, with higher scores indicating greater symptom severity (Gotham et al., 2009).

Leiter International Performance Scale - Third Edition (Leiter-3; Roid et al., 2013)

Designed for assessment of individuals between 3 and 75 years of age, the Leiter-3 is a nonverbal intellectual assessment commonly administered to ASD populations (Roid & Koch, 2017). It comprises 10 subtests which measure cognitive ability across three dimensions, including general IQ, nonverbal memory and processing speed (Roid & Koch, 2017).

Social Responsiveness Scale – Second Edition (SRS-2; Constantino & Gruber, 2012)

The SRS-2 is a 65-item informant-completed rating scale of socially relevant behaviours in ASD that includes both preschool (2:6 to 4:6 years) and school-age (4:0-18:0 years) forms that can be rated by parents and teachers. Items are summed to calculate scores in the domains of Restricted Interests and Repetitive Behaviour (RRB) and Social Communication and Interaction (SCI), which combine to an overall Total Score (Constantino & Gruber, 2012). Results are reported as T-scores, with scores above 75 indicating severe social deficits, scores between of 66 to 75 considered moderate, scores of 60 to 65 considered mild, and scores below 60 indicate no socially challenged behaviour related to ASD (Bruni, 2014).

2.2.3. Eye-Tracking Task

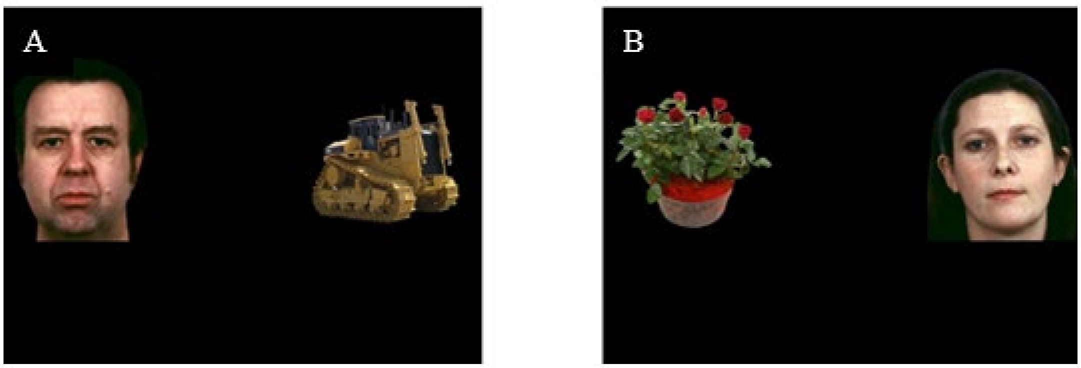
The current study employed the visual preference task developed by Sasson and Touchstone (2014; Figure 2.1). The HAI and LAI objects used in this task were previously validated to be of CI and non-CI interest, respectively, across childhood (South et al., 2005). Participants were presented with one block of 20 randomly presented slides of a social image (a face) paired with a HAI (i.e., CI) or LAI object. Neutral, happy, sad, angry, and fearful emotional expressions were each presented four times. Social and object images did not repeat, and their location was counterbalanced between the right and left sides of the screen. Participants sat on a booster chair fitted on a regular office chair, or a regular height-adjustable office chair, and were positioned approximately 65 cm away from a 23-inch computer monitor with a pixel resolution of 1920 x 1080. The monitor was integrated with the Tobii TX300 eye tracker (Tobii Technology, Stockholm, Sweden), which was used to collect eye tracking data with a sampling rate of 300Hz and spatial accuracy of 0.4 degrees.

Participants completed a 9-point calibration procedure. Once calibration was successfully completed, participants were told they would be looking at some pictures and could look wherever they wanted. Prior to the first paired social and object image slide being presented, an introductory slide reading "Hi, let's start" was presented to orient attention to the screen. A slide reading "You're doing really well" was presented half-way through the task to maintain attention to the screen, and a final slide reading "Well done! You're finished" marked the end of the task. The presenter would read aloud these written prompts as each of these slides were presented to reinforce and tailor the message for participants who were illiterate. Each slide was presented for 5 seconds, followed by an interstimulus interval (ISI) of an animated figure presented centrally for 500ms to encourage task engagement. The total duration of the task was approximately 1 minute and 20 seconds.

An I-VT filter was applied to raw data, using a velocity threshold of 30 degrees/second and a minimum fixation duration of 60ms (Tobii Technology AB, 2016). Areas of Interest (AOIs) were drawn around each face and object image. Face and object AOIs approximated 15% and 12% of the screen, respectively. Eye tracking variables were aggregated using Tobii Studio Version 3.4.8 (Tobii Technology AB, 2016). Overall, 20 participants did not have eye tracking data collected. Technical issues prevented task administration for sixteen participants and calibration could not be completed with four participants due to noncompliance. The data from an additional two participants were excluded from analyses as the quality of their gaze data fell below the 20% threshold adopted in this study, and used in prior studies (for example, (Harrop et al., 2018a).

Figure 2.1

Visual Preference Task



Note. Example images from the visual preference task developed by Sasson and Touchstone (2014). (A) Image of a face paired with a HAI; (B) Face paired with a LAI. HAI, high autism interest; LAI, low autism interest.

2.2.4. Data Analysis

Similar to previous studies employing this task (Harrop et al., 2018a; Sasson & Touchstone, 2014; Unruh et al., 2016), the following dependent variables (DVs) were analysed as measures of social and object attention: (1) Prioritisation, the latency to first fixate to the face or object; (2) Preference, the proportion of total fixation duration to the face or object relative to total fixation duration to the AOIs on the screen; and (3) Duration, the total fixation duration to the face or object across all trials.

Initial exploratory analyses indicated a non-normal distribution of data for the prioritisation DV only; log transformations were therefore performed, although significant improvements in normality were not observed. As subsequent non-parametric and parametric analyses yielded similar results, parametric results are reported. Repeated-measures analyses of variance (RM-ANOVAs) were conducted on each DV with object type (HAI, LAI) as the within-group variable, and diagnosis (ASD, TYP) as the between-group variable. Greenhouse-Geisser corrections were applied as the assumption of sphericity was violated. Exploratory analyses using Spearman's rank order correlations were conducted between eye-tracking DVs and the ADOS-2 CSS for Total, SA and RRB domains, and with the SRS-2 Total, SCI and RRB domain T-scores. Data were analysed using IBM SPSS Version 26® (IBM Corp, 2019).

2.3. Results

2.3.1. Preliminary Analysis on the Effects of Sex, Age, and Non-Verbal IQ

Given the proportion of male and female participants across both groups, separate univariate analyses of variance (ANOVAs) with sex as the between-subjects factor were conducted on each DV (prioritisation, preference, duration) within both groups. These analyses confirmed no significant effect of sex on any eye-tracking DV within the ASD group ($p \geq .271$ for all analyses). Likewise, within the TYP group, there was no significant effect of sex on eye tracking variables ($p \geq .070$). Age was not included as a covariate due to non-significant differences in mean ages between groups and analyses of scatterplots indicated that the assumption of linearity between age and eye-tracking DVs was not met. Similarly, non-verbal IQ was not included as a covariate as correlational analyses indicated no significant associations with any eye-tracking DV across ASD or TYP groups. Although eligibility criteria did not exclude individuals with lower IQs, only two participants scored below 70 for non-verbal IQ, precluding analysis of differences in gaze behaviour based on this characteristic. Analyses were conducted with and without these participants and the pattern of results remained the same, hence results are reported inclusive of these participants.

2.3.2. Group Differences in Eye-Tracking Variables

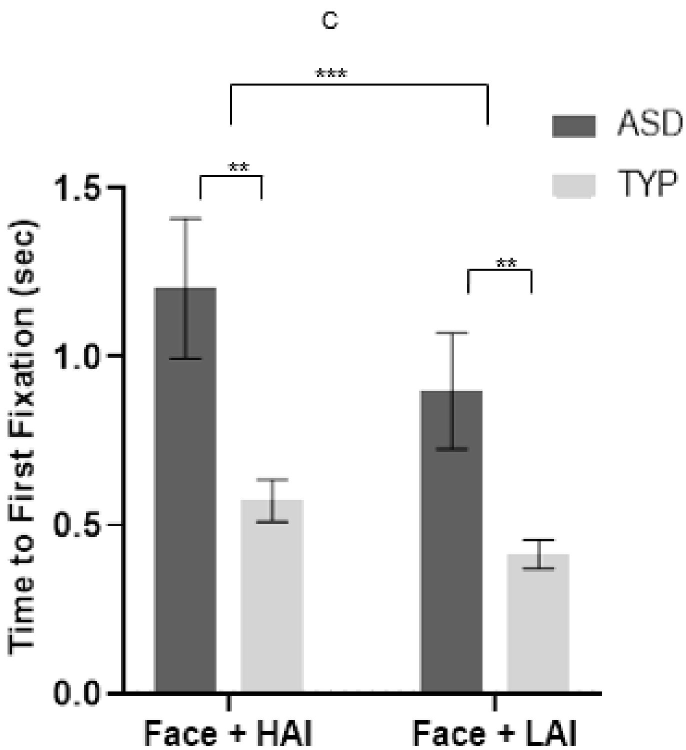
2.3.2.1. Prioritisation

Faces: Results from a 2 x 2 RM-ANOVA indicated no significant object type x diagnosis interaction effect, $F(1,64) = 1.799$, $p = .354$, $\eta^2_p = .013$. There was a significant main effect of object type, $F(1, 65) = 8.841$, $p = .004$, $\eta^2_p = .120$, and a significant main effect of diagnosis, $F(1,65) = 7.526$, $p = .008$, $\eta^2_p = .104$, with the ASD group taking longer to look to the face compared to the TYP group ($M_{diff} = .557$, $SE = .203$, $p = .008$). Group differences for each object type are illustrated in Figure 2.2. Post-hoc analyses revealed that both ASD and TYP took longer to prioritise the face when paired with an HAI compared to LAI object (ASD: $M_{diff} = .305$, $SE = .137$, $p = .033$; TYP: $M_{diff} = .159$, $SE = .037$, $p < .001$).

Objects: A 2 x 2 RM-ANOVA revealed no significant object type x diagnosis interaction effect $F(1,65) = 2.425$, $p = .124$, $\eta^2_p = .036$. There was a significant main effect of object type $F(1,65) = 23.916$, $p < .001$, $\eta^2_p = .269$. Pairwise comparisons demonstrated that both groups fixated faster to HAI compared to LAI objects ($M_{diff} = .314$, $SE = .064$, $p < .001$). A trend for the main effect of diagnosis, $F(1, 65) = 3.938$, $p = .051$, $\eta^2_p = .057$, indicated the TYP group may have prioritised objects faster than the ASD group ($M_{diff} = .393$, $SE = .198$, $p = .051$).

Figure 2.2

Social Prioritisation Across HAI and LAI Conditions



Note. Mean (+/- standard error) time to first fixation in seconds to faces adjacent to HAI and LAI objects in ASD and TYP groups. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.
** $p < .05$, *** $p < .001$.

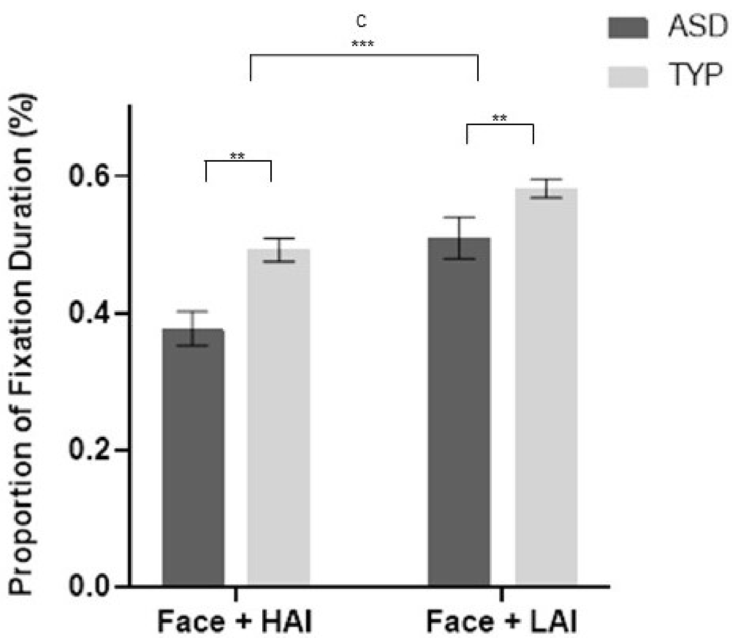
2.3.2.1.1. Preference

Faces: A 2 x 2 RM-ANOVA demonstrated a significant object type x diagnosis interaction effect, $F(1,65) = 6.018$, $p = .017$, $\eta^2_p = .085$ (Appendix B, Figure 1A). Significant main effects were found for both object type $F(1,65) = 112.397$, $p < .001$, $\eta^2_p = .634$ and diagnosis $F(1,65) = 5.588$, $p = .021$, $\eta^2_p = .079$. Group differences for both object types are shown in Figure 2.3. Overall, the TYP group demonstrated greater preference for faces regardless of object type ($M_{diff} = .094$, $SE = .031$, $p = .005$). Both groups displayed less preference for the face when paired with HAI compared to LAI objects (M_{diff} = 0.111, *SE* = .013, p < .001). Follow up analyses indicated that the interaction effect was driven by the TYP group spending significantly more time fixating on faces during HAI trials than the ASD group (p = .001), while no significant group difference was evident during LAI trials (p = .241).

Objects: A 2 x 2 RM-ANOVA resulted in a significant object type x diagnosis interaction effect, F(1,65) = 6.018, p = .017, η^2_p = .085 (Appendix B, Figure), with follow up analyses indicating the ASD group had a significantly greater preference for HAI objects compared to the TYP group, (p = .001) while there was no group difference in the preference for LAI objects (p =.214). Pairwise comparisons revealed an overall higher preference to view objects in the ASD group (M_{diff} = 7.047, *SE* = 2.981, p =.021), while both groups had a preference to view HAI over LAI objects (M_{diff} = 13.568, *SE* = 1.280, p < .001).

Figure 2.3

Social Preference Across HAI and LAI Conditions



Note. Mean (+/- standard error) proportion of fixation duration in seconds to faces adjacent to HAI and LAI objects in ASD and TYP groups. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.
*** $p < .001$. ** $p < .05$.

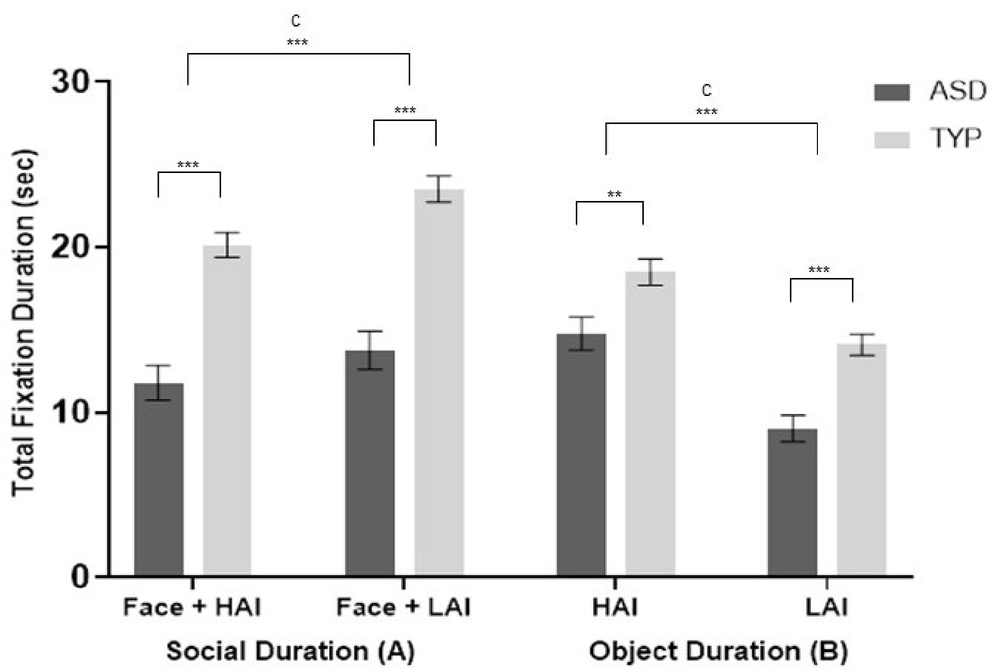
2.3.2.1.2. Duration

Faces: A 2 x 2 RM-ANOVA revealed no significant interaction effects, $F(1,65) = 3.144$, $p = .081$, $\eta^2_p = .046$. Significant main effects were demonstrated for both object type, $F(1,65) = 44.013$, $p < .001$, $\eta^2_p = .404$, and diagnosis, $F(1,65) = 44.581$, $p < .001$, $\eta^2_p = .407$. Pairwise comparisons indicated shorter fixation durations to faces in the presence of HAI objects for both groups ($M_{diff} = 2.672$, $SE = .405$, $p < .001$), and the TYP group demonstrated longer fixation durations to faces compared to the ASD group ($M_{diff} = 8.944$, $SE = 1.375$, $p < .001$).

Objects: There was no significant object type x diagnosis interaction for the duration of fixations to objects, $F(1,64) = 2.404$, $p = .126$, $\eta^2_p = .036$. Significant main effects for object type, $F(1,65) = 44.013$, $p < .001$, $\eta^2_p = .404$, and diagnosis, $F(1,65) = 44.581$, $p < .001$, $\eta^2_p = .407$ were found. Pairwise comparisons revealed greater fixation durations to HAI compared to LAI objects for both groups, $M_{diff} = 2.676$, $SE = .403$, $p < .001$, and the TYP group displayed greater fixation durations to both object types compared to the ASD group, $M_{diff} = 9.064$, $SE = 1.358$, $p < .001$. Figure 2.4 illustrates group differences in fixation duration to both faces and objects. Table 2.2 lists the means (SD) of eye-tracking DVs across ASD and TYP groups.

Figure 2.4

Duration of Fixations to Faces and Objects Across HAI and LAI Conditions



Note. Mean (+/- standard error) total duration of fixations to face and object stimuli in ASD and TYP groups. (A) Total fixation duration to face adjacent to HAI and LAI objects. (B) Total fixation duration to HAI and LAI objects. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.

*** $p < .001$. ** $p < .05$.

Table 2.2

Mean (SD) in Seconds of Eye Tracking Variables in ASD and TYP Groups

Eye tracking variables	**TYP (*n* = 30)**	**ASD (*n* = 37)**
	Mean (*SD*)	**Mean (*SD*)**
Prioritisation		
Faces		
Overall	.45(.26)	1.04(1.16)
Face + HAI	.57(.34)	1.20(1.27)
Face + LAI	.41(0.24)	.90(1.05)
Objects		
Overall	.70(.22)	1.14(1.23)
HAI	.61(.31)	0.90(.92)
LAI	.82(.27)	1.32(1.27)
Preference		
Faces		
Overall	57.31 6.18	49.32 (15.35)
Face + HAI	52.17(8.84)	41.99(15.17)
Face + LAI	62.60(6.69)	58.70(17.34)
Objects		
Overall	42.69(6.18)	50.68(15.35)
HAI	47.87(8.84)	58.01(15.17)
LAI	37.40(6.69)	41.30(17.34)
Duration		
Faces		
Overall	43.66(7.44)	25.53(13.27)
Face + HAI	20.13(4.15)	11.78(6.40)
Face + LAI	23.52(4.35)	13.74(7.06)
Objects		

Overall	32.57(6.92)	23.78(10.47)
HAI	18.48(4.37)	14.77(6.10)
LAI	14.09(3.54)	9.01(4.95)

Note. TYP, Typically Developing; ASD, Autism Spectrum Disorder; HAI, High Autism Interest; LAI, Low Autism Interest.

2.3.3. Correlations Between Eye-Tracking Variables and Clinical Measures

Within the ASD group, there were significant medium sized negative correlations between ADOS-2 CSS RRB scores and fixation duration to faces across object types (ρ = -.339, p = .040), and fixation duration to faces adjacent to LAI objects (ρ = -.401, p = .014), indicating that greater attention to faces overall and in the presence of LAI objects, was associated with a lower severity of restricted and repetitive behaviours. A similar correlation was not found for faces adjacent to HAI objects. One additional statistically significant correlation between ADOS-2 Total CSS and fixation duration to HAI objects (ρ = -.335, p = .043) was found, suggesting greater symptom severity was associated with less attention to HAI object.

Baseline significant differences in Total, SCI and RRB domain scores of the SRS-2 demonstrated greater impairment in the ASD compared to the TYP group across all three domains. For the ASD group, significant medium sized negative correlations between fixation duration to LAI objects and RRB (ρ = -.343, p = .038), SCI (ρ = -.353, p = .032) and Total scores (ρ = -.360, p = .029) demonstrated that greater attention to LAI objects was associated with higher functioning overall and in behaviours related to social communication and interaction skills, and repetitive behaviours and restricted interests. No significant correlations between attention measures and SRS-2 scores were found for HAI objects or the TYP group. The correlations between eye-tracking DVs and ADOS-2 and SRS-2 scores for the ASD group are details in Table 2.3.

Table 2.3

Spearman's Correlations Between Eye-tracking Variables, Symptom Severity and Social Functioning in the ASD Group

Eye tracking variables	ADOS-2 CSS			SRS-2		
	Total	SA	RRB[1]	Total	SCI	RRB[2]
Prioritisation						
Faces						
Overall	.057	.023	.117	-.004	.011	-.050
Face + HAI	.072	.108	-.133	.058	.063	.050
Face + LAI	.058	-.019	.250	-.022	-.014	-.043
Objects						
Overall	.110	.070	.181	.128	.119	.178
HAI	.215	.168	.141	.164	.164	.200
LAI	-.159	-.173	.053	-.035	-.051	.034
Preference						
Faces						
Overall	-.140	-.106	-.109	.059	.089	-.057
Face + HAI	.041	-.037	-.012	-.031	-.009	-.080
Face + LAI	-.123	-.056	-.171	.185	.215	-.020
Objects						
Overall	.140	.106	.109	-.059	-.089	.057
HAI	.041	.037	.012	.031	.009	.080
LAI	.123	.056	.171	-.185	-.215	.020
Duration						
Faces						
Overall	-.177	-.118	-.339*	-.203	-.197	-.228
Face + HAI	-.086	-.046	-.242	-.213	-.199	-.234
Face + LAI	-.231	-.153	-.401*	-.175	-.170	-.220

Objects						
Overall	-.322	-.325	-.243	-.266	-.255	-.287
HAI	-.335*	-.317	-.295	-.229	-.216	-.275
LAI	-.266	-.288	-.162	-.360*	-.353*	-.343*

Note. ASD, autism spectrum disorder; ADOS-2, autism diagnostic observation schedule – second edition; CSS, calibrated severity score; SA, social affect; RRB[1], repetitive and restricted behaviours; SRS-2, social responsiveness scale – second edition; SCI, social communication and interaction; RRB[2], restricted interests and repetitive behaviours.

* $p < .05$.

2.4. Discussion

Using an established visual preference eye-tracking task, the purpose of this study was to investigate the contextual influence of circumscribed interests (CIs) on patterns of social and object attention in children with ASD and their TYP peers, and the relationship between these patterns and social functioning more broadly. In support of our first hypothesis, results demonstrated reduced attention to social stimuli in children with ASD compared to TYP children, regardless of the presence of HAI objects (representing CIs). Reduced attention in the ASD group also extended to non-social stimuli, a surprising finding of the study. Analysis of attention patterns indicated that both ASD and TYP groups appeared to be influenced by CIs. That is, both groups exhibited reduced social attention and increased non-social attention in the presence of CIs, in line with our second hypothesis. Among participants with ASD, correlational analyses indicated that greater attention to faces overall and in the presence of LAI objects was related to less severe restricted and repetitive behaviours as measured by the ADOS-2, while greater fixation duration to LAI objects was significantly associated with greater social functioning, as measured by the SRS-2.

Reduced social attention was evident in children with ASD across all three attention measures. Overall, children with ASD were significantly slower in prioritising the face; similarly, their preference to attend and maintain attention to faces was significantly reduced compared to TYP children across object types. Although the contextual influence of CIs did influence the preference to attend to faces in the current study, this finding did not extend to the social prioritisation and duration of attention variables. These results contrast with Sasson and Touchstone (2014) where reduced social attention in pre-schoolers with ASD was only evident when paired with objects related to CIs (i.e., HAIs). The specific influence of CIs on social prioritisation, preference and duration variables lead to their conclusion that social attention is influenced by the nature of stimuli competing for attention in this population, rather than a global social saliency deficit as postulated by the social motivation hypothesis (Sasson & Touchstone, 2014). However, the broader reductions in social attention patterns in children with ASD demonstrated in this study are supportive of more recent studies (Harrison & Slane, 2020; Mo et al., 2019; Unruh et al., 2016), and meta-analytic findings of atypical gaze patterns towards social stimuli (Chita-Tegmark, 2016b; Frazier et al., 2017), supporting overall reductions in social attention irrespective of the salience of competing stimuli.

Surprisingly, object-directed attention mirrored social attention patterns across both groups of participants. The overall duration of attention to both object types was reduced in children with ASD. Although decreased attention to LAI objects could be reasonably expected (Anderson et al., 2006; Sasson et al., 2011), the finding of overall decreased attention to HAI objects is interesting considering the breadth of literature supporting the increased salience of CIs in this population (Harrop et al., 2018a; Manyakov et al., 2018; Sasson et al., 2011; Sasson & Touchstone, 2014; Traynor et al., 2019; Unruh et al., 2016). A similar trend was observed for the prioritisation of objects, with the TYP group taking a significantly shorter amount of time to fixate to either object type, a result consistent with the other main findings of this study. Reduced object-directed attention in ASD has been reported cross-modally (Keehn et al., 2016; Keehn et al., 2017; Parsons et al., 2017). In eye-tracking for example, Parsons et al. (2017) investigated the distribution of attention to object and social stimuli in infants at high and low familial risk of ASD and found that high risk infants later diagnosed with ASD engaged less with objects and this was associated with poorer future vocabulary skills. Supporting this, neurophysiological and neurological evidence of under-reactivity or hypoactivation of attentional networks in response to both social and object stimuli has been replicated across studies, suggesting that differences in attention across social and non-social domains may be implicated in ASD (Clements et al., 2018; Dichter et al., 2010; Keehn et al., 2016; Keehn et al., 2017; Richey et al., 2014).

An increased influence of CIs in the attentional patterns of children with ASD was evident in the reduced preference to attend to faces and increased preference to attend to HAI objects in that condition. This finding, which extends the results of Sasson & Touchstone (2014) in toddlers to a broader age cohort across childhood in ASD, suggests that CIs core to ASD do elicit a relative preference to attend to HAI stimuli. However, in this study the influence of CIs was shared across groups with both ASD and TYP children spending less time looking at faces and more time looking at HAI objects. Similarities in the influence of CIs on attention patterns across ASD, TYP and Broad Autism Phenotype (BAP) groups have also been reported in other studies (Goldberg et al., 2017; Morrison et al., 2018; Sasson et al., 2008; Silver et al., 2020). A recent study by Silver et al. (2020), investigated whether children and adults with ASD demonstrated an advantage in the visual processing of CIs and found no differences between ASD and TYP groups in the early visual perception of CIs, but surmised these interests may interfere with later processing streams involved in cognitive control and arousal. These findings also raise questions regarding the contexts and cognitive mechanisms subserving the influence of CIs on atypical attention processes specifically, and socio-cognitive processes and social functioning more generally, in ASD.

The shared influence of CIs across groups and attention variables, and overall reduced attention patterns in the ASD group may also be suggestive of a conceptual and neurocognitive divergence in gaze behaviour to social and CI-related stimuli. Recent studies in both children and adults with ASD and their neurotypical peers have demonstrated that an increased preference for HAI objects was not due to an avoidance of social stimuli (Gale et al., 2019; Manyakov et al., 2018), contributing to the possibility that the increased salience of CIs is conceptually and operationally distinct from the salience of social stimuli such as faces (Bottini, 2018).Although not the focus of this study, abnormalities in the early development and regulation of attentional control and disengagement behaviours have led some researchers to hypothesise a different conceptual framework for understanding shared arousal mechanisms concurrent with atypical attention disengagement and attention shifting mechanisms between social and non-social stimuli in ASD (Keehn et al., 2013). While altered visual processing mechanisms may lead to an overall reduction in attention in ASD (Bellocchi et al., 2017), as seen in this study, the increased salience of CIs under some conditions may partly explain the heterogeneity reported across different studies, providing further impetus for employing multimodal methods investigating underlying neurocognitive process in CI-related visual attention patterns across neurodevelopmental and typically developing cohorts.

In the current study, increased attention allocation to faces overall, and adjacent to LAI objects, was associated with reduced symptom severity in restricted and repetitive behaviours.

Furthermore, greater attention to LAI objects directly was associated with higher social skills and milder restricted and repetitive behaviours in children with ASD. While these results appears to be in contrast with previous research highlighting a positive association between social impairment and object-directed attention (Klin et al., 2002; Pierce et al., 2016; Rice et al., 2012), they could potentially reflect that greater task engagement, is associated with better social functioning. A similar conclusion was drawn in a social skills intervention study with findings suggesting that higher social functioning in individuals with ASD was associated with increased attention to faces and background objects (Greene et al., 2020). Neurologically, the under-reactivity of biomarkers of arousal and attention has also been associated with atypical attention to behaviourally relevant social and non-social stimuli and ASD symptomatology (Bottini, 2018; Keehn et al., 2016; Keehn et al., 2017), providing additional support for the suggestion that both social and non-social visual attention processes may play a complementary role in the social communication and functioning challenges commonly found in individuals with ASD. Due to the small sample size and exploratory nature of the correlational analyses in this study, results should be interpreted with caution and require replication. However, in the future, a larger study investigating task orientation and engagement as a predictor of social functioning and repetitive and restricted behaviours may reinforce some the clinical associations found in this study and disentangle some of the existing heterogeneity in this research area.

There are several other limitations in the present study that warrant consideration. Due to a relatively small sample size, within- and between-group sex differences in social and object attention patterns could not be investigated. As most of the participants in the ASD group were male, and previous research has evidenced similarities in social attention patterns in the presence of CIs in female participants with and without ASD (Harrop et al., 2018a, 2018b), the results of this study may be more applicable to males. Second, the visual preference task administered included object AOIs which shared a relatively smaller proportion of the screen compared to face AOIs. Hence, it is possible that perceptual differences biased differences in attention patterns to social and non-social stimuli, cautioning interpretation of any main effects of object type. As the aim of this study was to investigate the influence of CIs on social and non-social attention patterns, the task was not suited to determine overall reductions in attention. Future studies could incorporate task paradigms designed to probe overall changes or reductions in attention across groups. Additionally, the type of CIs used may have influenced the attention patterns reported in this study. Although the CIs used in this task have been validated across childhood in ASD (South et al., 2005), gender differences in CIs (Harrop et al., 2019; Nowell et al., 2019) , and the use of personalised over non-personalised CIs (Harrison & Slane, 2020; Traynor, 2019), have previously been shown to influence social attention patterns in ASD cohorts. The growing number of studies in this area of research suggests a systemic review on the influence of CIs on social attention patterns across childhood in ASD is warranted.

The results of the current study contribute to a growing body of evidence of atypical attention patterns to both social and object stimuli, supportive of the hypothesis that attention atypicalities demonstrated in ASD extend beyond the social domains suggested by the social motivation hypothesis (Bottini, 2018; Chevallier et al., 2012; Clements et al., 2018; Keehn et al., 2016). The results may also suggest that objects common to CIs in children with ASD may play a more general role in influencing their attention patterns and those of their typically developing peers. Indeed, attention to behaviourally or task-relevant stimuli including both social and non-social content may be more instrumental in the day-to-day social and adaptive challenges experienced by children with ASD than is currently understood. Specific to CIs, future cross-modal research, implementing static, as well as dynamic and interactive task paradigms (e.g., (Chevallier et al., 2015) may also facilitate a deeper understanding of the operational influence of CIs on early and later stage socio-cognitive processes and how this may change over the course of childhood. Developing a deeper and more robust model of contextual variations to attention patterns throughout development would contribute to our overall understanding of this important behavioural phenotype, and to future research investigating the implications of atypical gaze behaviour in the diagnosis and treatment response of children with ASD.

2.5. References

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3. An Investigation of Social and Joint Attention Behaviours During Shared Book Reading: An Eye-Tracking Study

Preface

As discussed in Chapter 1, social attention, including joint attention, are pivotal social behaviours that have been widely reported to diverge in autistic children compared to their neurotypical peers. These social behaviours have predominantly been measured using eye-tracking methods including static and dynamic contexts. However, the field has been hindered by inconsistent findings and use of simplistic experimental paradigms lacking ecological validity or developmental relevance to young children, thereby challenging the generalisation of findings to real-world settings. These issues are particularly relevant to eye-tracking studies of joint attention, where most tasks are designed to measure only specific components of joint attention, in contrast to more realistic approaches that capture its conceptual framework. Thus, the objective of the study described in chapter 3 was to develop a novel, experimental paradigm for eye-tracking that was designed to capture social and joint attention behaviours in young autistic children with greater ecological, developmental, and conceptual validity. A shared book reading (SBR) paradigm was selected given the inherently social nature of this frequently adopted early childhood activity across home and school settings, and it's reported importance to development and adaptive functioning outcomes across neurodevelopmental and neurotypical populations.

Abstract

In the last two decades, eye-tracking has evolved as a popular method for investigating attention to social and joint attention behaviours in autistic children. Although atypicalities in attention have been reported, inconsistent findings have highlighted the need for investigating these behaviours using ecologically and developmentally relevant experimental paradigms. In this study, a novel, dynamic eye-tracking task involving a shared book reading (SBR) scenario in a naturalistic setting was developed to investigate social and joint attention behaviours in a young cohort of autistic children (*N* = 56, 3-12 years) and their age-matched neurotypical peers (*N* = 34). Compared to neurotypical children, autistic children displayed reduced attention to salient features of the scene including the face of the adult reader and SBR activity, while exhibiting increased attention to non-salient background objects of the scene. These patterns of attention were evident in the task overall and during episodes of joint attention. Results also demonstrated some associations with receptive language skills and autism symptomatology. The SBR paradigm developed may address an important limitation in eye tracking studies, providing a generalisable context for investigating these uniquely social behaviours in young autistic children.

3.1. Introduction

Social communication and interaction challenges comprise one of the main diagnostic domains of autism spectrum disorder (ASD). Within this domain, an important behavioral phenotype evident throughout development is atypicality in gaze behaviours in relation to social cues (Frazier et al., 2017; Tiede & Walton, 2020). From early in life, young children who are at high risk for, or receive an ASD diagnosis, demonstrate diminished attention to eyes and faces (Chita-Tegmark, 2016a; Frazier et al., 2017). It is also common for these children to engage atypically with, or in response to people or social interactions (Avni et al., 2019; Chawarska et al., 2012), and demonstrate reduced joint attention behaviours (Swanson & Siller, 2013; Vivanti et al., 2017). In turn, these and other atypicalities in social attention are suggested to hinder the typical development of cognitive (Latrèche et al., 2021), socio-cognitive (Brooks & Meltzoff, 2015), language and literacy skills (Bradshaw et al., 2019; Mundy et al., 2007; Stagg et al., 2014), and potentially lead to poorer social and adaptive functioning both in the short term (Del Bianco et al., 2020; Riddiford et al., 2022; van Rijn et al., 2019), and long term (Latrèche et al., 2021; Wagner et al., 2018).

In recent years, eye tracking has emerged as a valuable tool for investigating gaze behaviours in this population, and their relationship to child development more broadly (Carter & Luke, 2020; Hamner & Vivanti, 2019; Venker & Kover, 2015). Overall, this research has demonstrated that autistic children do display atypical social attention patterns throughout childhood, and this may be predictive of the severity of their symptoms and developmental outcomes (Frazier et al., 2017; Riddiford et al., 2022). However, mixed findings are commonly reported (Frazier et al., 2017; Mastergeorge et al., 2020; Tsang et al., 2019). Some of this variability may be a result of experimental task design. For example, a growing number of studies have highlighted the need for the use of non-social distractor stimuli to demonstrate preference effects away from social stimuli (Chawarska et al., 2012; Klin et al., 2002; Mo et al., 2019). Other studies have highlighted the need to use developmentally appropriate tasks, that are relatable for the age group and population being studied (Ishizaki et al., 2021; Tsang et al., 2019). Researchers have also argued that some of these tasks lack ecological validity, making it difficult to extrapolate findings to real world settings (Kwon et al., 2019; Wang et al., 2020). The lack of ecological validity is particularly prevalent in tasks measuring joint attention behaviours, which predominantly focus on specific components of joint attention such as gaze cueing effects or attention to the target object (Cilia et al., 2019; Palomo et al., 2022; Swanson & Siller, 2013). Rarely, do these tasks capture joint attention as its conceptually understood, that is, the triadic, spatio-temporal process whereby the child follows the gaze (and commonly, gestures) of another, sharing in the experience of a common focus of interest (Mundy, 2018; Mundy et al., 2009). Well-designed tasks that can better capture developmentally appropriate and ecologically valid social behaviours may overcome some of these limitations.

In this regard, one of the most common and widely adopted social activities shared by parents or educators and children is shared book reading (SBR). Universally adopted, SBR is highly adaptable across educational and home environments (He & Bowman, 2021; Kibler et al., 2020; Korat et al., 2013; Rodríguez et al., 2009; Sun et al., 2020). In educational settings, SBR is often the language-based activity of choice and has been recommended for daily practice in early childcare settings (AIHW, 2020; Dickinson & Porche, 2011; Hadley et al., 2022). In the home, parents frequently participate in SBR, especially in early childhood, and parental engagement in SBR is considered instrumental in the development of a wide range of language and literacy skills (Anderson et al., 2019; Bus et al., 1995; Hayes & Berthelsen, 2020; Kassow, 2006; Sénéchal & LeFevre, 2002). These skills include vocabulary (Bus et al., 1995; Flack et al., 2018; Mol et al., 2009; Saracho, 2020; Sénéchal & LeFevre, 2002), print and phonological awareness (Justice & Ezell, 2004; Lefebvre et al., 2011), grammar (Valdez-Menchaca & Whitehurst, 1992), reading and story comprehension (Mol & Bus, 2011), and narrative and causal reasoning (van der Wilt et al., 2022). Longitudinal research has also indicated that the benefits of reading in the early years compound, resulting in improved outcomes in literacy, language, and overall academic achievement (Farrant & Zubrick, 2013; Mol & Bus, 2011). Additionally, SBR practices in early childhood have been found to be associated with higher executive function (Hayes & Berthelsen, 2020; Kuhn et al., 2014) and joint attention behaviours (Guo, 2012; Zimmer, 2015).

Due to the characteristic difficulties in language, literacy, joint attention and social interaction experienced by autistic children, recent years have seen researchers investigating the benefits of SBR intervention (D'Agostino et al., 2020; Fleury et al., 2021; Simpson, 2020; Westerveld et al., 2020; Zimmer, 2015, 2017). A range of SBR interventions have been developed to promote social initiation (D'Agostino et al., 2020), shared interaction with caregivers (Zimmer, 2017), and the development of communication, language and literacy skills in this population, with overall positive effects (Akemoglu & Tomeny, 2021; Henry et al., 2021; Jackson et al., 2022; Kim et al., 2018; Nunes et al., 2021; Phalen & Chezan, 2022; Whalon, 2018). A recent meta-analysis of 11 studies contributed further evidence supporting the use of SBR to improve comprehension and communication skills in autistic children (Boyle et al., 2019). Furthermore, promising evidence that suggests that SBR may also be beneficial in improving joint attention skills in this population (Caldas & Flores, 2021; Wicks et al., 2022; Zimmer, 2015).

While SBR is principally implemented to foster the development of language and communication skills, it is by nature a social engagement activity. In real-world settings, SBR activities are likely to be accompanied by multiple competing distractors that are present in the surrounding environment. As such, a degree of, natural flexibility and sustained attention is required between the book, the child and the parent or educator, as they read through the story. To this end, parents or educators often implement strategies such as extra-textual talk, including comments and questions, and gestural points in order to encourage engagement, highlight important elements of the story, as well as promote story comprehension (de Villiers Rader et al., 2021; Ezell & Justice, 2005; Hoel et al., 2020). In this way, SBR provides a natural framework for exploring dyadic engagement and joint attention behaviours in ecologically relevant contexts including both social and non-social cues. Thus, employing SBR as an experimental paradigm to investigate social attention and communication behaviours may be advantageous in gaining a better understanding of how these behaviours are associated with the development of children's cognitive, social, and adaptive functioning skills. As such, further research is needed to provide the basis for the development of more evidence-based interventions.

Although a significant body of research has reported on the use of different strategies within SBR to improve engagement, communication, and language outcomes in autistic children, comparatively less research has focused on their attention patterns during this activity. In neurotypical children, SBR studies using eye tracking have primarily focused on investigating the distribution of attention between illustrations and print. Results suggest that younger children (under the age of five) tend to direct more of their attention to illustrations rather than print (Evans & Saint-Aubin, 2005, 2013; Evans et al., 2008; Justice et al., 2008; Justice et al., 2005). In autistic children, there are only two known studies employing eye tracking to investigate attentional differences with neurotypical children during SBR (Thompson et al., 2019; Wicks et al., 2022). In those studies, attentional patterns to illustrations and print were examined in response to different types of prompts. One of those studies investigated these patterns in minimally verbal autistic children and showed overall low levels of attention across all stimuli (Thompson et al., 2019). In the other study, including autistic children of varying abilities, authors reported similar levels of attention to print and reduced attention to illustrations compared to their neurotypical peers (Wicks et al., 2022). A third study used behavioural coding of recorded interactions of children and caregivers engaging in SBR, and reported significant positive correlations between attention to the book, verbal utterances and parental engagement strategies (Wicks et al., 2020).

Notwithstanding the importance of investigating strategies to increase engagement in SBR, there are several reasons why understanding how autistic children naturally attend to the salient cues during SBR in the first instance is also relevant. Firstly, researchers have proposed that a divergence in the inferred saliency of cues is predictive of attentional patterns, rather than their categorisation as being social or non-social in nature (Constantino, 2017). This view has been supported by behavioural and neurological evidence of atypical social and non-social attention patterns, and disrupted connectivity across visual, salience and attentional networks in the brain (Ambarchi et al., 2022; Clements et al., 2018; Frazier et al., 2017; Keehn et al., 2016). Secondly, there are inherent difficulties in discriminating between perceived and actual visual engagement in books, particularly in children with low verbal or cognitive skills (Johnson et al., 2009; Kasari & Sigman, 1997; Thompson et al., 2019). Thirdly, some research suggests that greater interest in books is associated with improved language and literacy outcomes (Hart et al., 2016; Wainwright et al., 2020). Fourthly, as described above, SBR provides an opportunity to engage in rich social experiences which have been proposed to contribute to a range of social and adaptive functioning outcomes (Tang et al., 2017; Tillmann et al., 2019; van Rijn et al., 2019; Zaidman-Zait et al., 2020). Moreover, to gain a better understanding of the potential for SBR to improve joint attention skills, research examining how effectively autistic children engage in joint attention opportunities in SBR is needed (Guo, 2012). Taken together, these findings suggest that developing a better understanding of autistic children's visual attention patterns during SBR using eye tracking, may provide an objective measure of their engagement and interest in its most salient features. In turn, this may increase the predictive value of this commonly practiced educational activity in the broader developmental outcomes of these children.

3.2. The Current Study

To date, there has been minimal research investigating the attention patterns of autistic children during SBR. To the author's knowledge, there has been no research specifically investigating autistic children's attentional patterns to salient and non-salient stimuli in a naturalistic SBR context compared to neurotypical children. Moreover, while prior research has proposed that engagement in SBR may be associated with cognitive and other clinical characteristics related to child development, there appears to be no research reporting on these associations in this population. Thus, the current study aimed to address this gap by aiming using eye tracking to investigate differences in gaze behaviour, including joint attention, within a naturalistic SBR paradigm in a young cohort of autistic and age-matched neurotypical children.

More specifically, the aims of this study were to investigate the differences in attention to salient and non-salient stimuli in the scene in both cohorts. The salient stimuli involved the adult reader engaging in the SBR activity, and the non-salient stimuli were grounded in the background objects in the scene. Group differences in attentional patterns toward the scene were assessed in the video overall, as well as in episodes of the video involving joint attention and dyadic interactions. It was hypothesised that autistic children would exhibit reduced attention to salient stimuli overall, and in the joint attention and dyadic interaction episodes, compared to neurotypical children. Conversely, it was hypothesised that autistic children would display greater attention to non-salient distractor stimuli across these conditions. Another goal of the study was to explore how attention patterns related to important developmental characteristics, including autism severity, as well as cognitive and social functioning. However, the limited evidence base reporting on these associations in this context precluded any specific hypotheses being made.

3.3. Methods

3.3.1. Participants

Participants included 56 autistic children (Age: M = 6.93, SD = 2.76; Male = 47) and 34 age-matched neurotypical children (Age: M = 7.74, SD = 2.34; Male = 23). There were no significant differences in age (t = 1.42, p = .158), or gender (χ^2 = 2.37, p = .124, phi = .072) between groups. Participant characteristics are presented in Table 3.1.

Autistic children were recruited through the Clinic for Autism and Neurodevelopment Research (CAN Research) at the Brain and Mind Centre (BMC) of The University of Sydney. Neurotypical children were recruited through locally distributed flyers and by word-of-mouth as part of a larger study exploring typical social development across the same age cohort. The studies encompassing the current research project received approval from The University of Sydney Human Research Ethics Committee (HREC) (references 2013/502, 2013/341, HREC/18/RPAH/157). Written informed consent was obtained from caregivers prior to study enrolment.

Autistic children were included if they met criteria for an ASD diagnosis from an unstructured psychiatric interview and they scored above the ASD cutoff on the Autism

Diagnostic Observation Schedule – Second Edition (ADOS-2; Lord., 2012) by research-reliable assessors. Individuals were excluded if there was evidence of severe renal, hepatic, cardiovascular or respiratory illness as reported by a caregiver or through physical examination. Exclusion criteria for neurotypical children included caregiver reported neurodevelopmental or mental health diagnoses or severe physical illnesses (e.g., severe cardiac, hepatic, renal, respiratory illness).

Table 3.1

Participant Characteristics

Characteristic	ASD			TYP		
	N	*M (SD)*	Range	*N*	*M (SD)*	Range
Age, years	56	6.93(2.76)	3.14-12.81	34	7.74(2.34)	3.78–12.11
Male/Female	47/9	-	-	23/11	-	-
NVIQ						
Leiter-R NVIQ	37	98.65(13.47)	68-129	26	116.54(12.59)**	68-129
MSEL NVDQ	12	77.85(21.68)	51-112	-	-	-
NVIQ composite[a]	49	93.56(18.04)	51-129	26	116.54(12.59)**	97-151
Receptive Language						
PPVT-4 T-Score	26	87.15(28.98)	37-135	14	117.57(11.99)**	98-143
MSEL RL T-Score	12	29.92(12.31)	20-58	-	-	-
RL composite[b]	38	69.08(36.60)	20-135	14	117.57(11.99)**	98-143
ADOS CSS						
Total	55	7.53(1.63)	5-10	-	-	-
SA	55	7.38(1.88)	3-10	-	-	-
RRB	55	7.58(1.88)	1-10	-	-	-
SRS-2 Mean T-Scores						
Total	56	76.66(10.10)	56-90	31	47.26(7.39)**	38-64
SCI	56	75.89(10.13)	53-90	31	47.00(7.42)**	37-62

RRB	56	75.79(11.07)	44-90	31	48.52(8.90)**	41-80

Notes. ADOS-2, autism diagnostic observation scale – second edition; ASD, autism spectrum disorder; CSS, calibrated severity scores; MSEL, mullen scales of early learning; NVDQ, non-verbal developmental quotient; NVIQ, non-verbal IQ; PPVT-4, peabody picture vocabulary test – fourth edition; RL, receptive language; RRB, restricted and repetitive behaviours; SA, social affect; SCI, social communication index; SRS – 2; social responsiveness scale – second edition; TYP, neurotypical children.

[a] Non-verbal IQ composite inclusive of Leiter-R NVIQ and MSEL NVDQ scores, [b] RL composite inclusive of PPVT-4 T-scores and MSEL RL T-scores.

** Indicates a significant group difference at $p < .001$

3.3.2. Development of the SBR Task

3.3.2.1. Selection of Picture Books

Four age-appropriate picture books that were part of a series of children's books written and illustrated by the same author and illustrator, respectively, were selected to meet the aims of the study. Each picture book was 32 pages long, including a similar theme and storyline, with illustrations that the adult reader could point to that clearly matched the sentences on the page being read. These books were: If you give a cat a cupcake (Numeroff & Bond, 2008), If you give a dog a donut (Numeroff & Bond, 2011), If you give a mouse a brownie (Numeroff & Bond, 2016), and If you give a pig a pancake (Numeroff & Bond, 1998).

The text features across all four picture books were consistent. Both the font and size of the text were equivalent on each page and across each picture book. No words or sentences were highlighted, characterised, or enlarged, thereby eliminating any textual features that would artificially attract the reader's attention to a greater degree than other text. A linguistic analysis of the text was conducted using Linguistic Inquiry and Word Count (LIWC; Pennebaker, Booth & Francis, 2007), and indicated that the linguistic features of each book (including, word count, words per sentence, affect, positive and negative emotion) were consistent across all four books. Similarly, consistency in the readability across books was analysed using The Readability Test Tool, an online readability tool (https://www.webfx.com/tools/read-able/). Flesch-Kincaid (FK) Reading Ease scores ranging from 94.3 to 103.4 (M = 98.93, SD = 3.73) and Grade Level scores ranging from 1.3 to 2.5 (M = 1.9, SD = .49) were obtained. A summary of the linguistic complexity and readability variables are presented in Table 3.2 and indicate acceptable values across examined variables.

Table 3.2

Linguistic Characteristics of the Four Picture Books

Picture Book	WC[a]	WPS[a]	Affect[a]	Positive emotions[a]	Negative emotions[a]	FK reading ease[b]	FK grade level[b]
If you give a dog a donut	257	10.28	1.56	1.17	.39	98.6	1.9
If you give a cat a cupcake	335	10.15	1.19	0.90	.30	103.4	1.3
If you give a mouse a brownie	299	10.68	2.01	2.01	.00	99.4	1.9
If you give a pig a pancake	302	10.07	1.99	1.66	.33	94.3	2.5

Notes. FK, flesch-kincaid; LIWC, Linguistic Inquiry; WC, Word count; WPS, words per sentence.

[a] data obtained from LIWC, [b] data obtained from The Readability Test Tool

3.3.2.2. Development of the SBR Videos

Four videos were developed, one for each picture book selected. Each video included the same actor, who was paid to be the adult reader in this SBR task. To standardise the development of each video, the actor was provided with four different scripts prior to the day of filming for review. Each script included the text from the picture book as well as prompts for when the actor needed to pause reading from the picture book and direct their gaze to the camera to initiate an episode of joint attention (JA) or a perceived bid to engage in a dyadic interaction (DB) (Appendix C). During the filming of each video, the actor read from the picture book in a natural manner, maintaining a consistent pace and volume. A researcher stood behind the camera and cued the actor using flash cards to initiate a JA or DB episode.

Each video included eight episodes of JA. Each JA episode was comprised of a 3-sequence event: 1) the adult reader directing their gaze at the camera and providing a verbal prompt relating to the text just read in a bid to engage in JA (for example, "look at all the sprinkles")(Figure 3.1); 2) the adult reader providing an explicit cue by directing their gaze and pointing to the target illustration in the picture book that was the subject of the extra-textual question or comment (i.e., the sprinkles)(Figure 3.2); and 3) the adult reader returning their gaze to the camera with the perceived intention of acknowledging shared awareness of the target illustration (Figure 3.3). The target objects of JA were illustrations rather than text to account for individual and group differences in word knowledge, and children's preference to attend to illustrations over print (Evans & Saint-Aubin, 2005; Wicks et al., 2021). Within each video, the side of the book involving a point gesture (left or right), target illustration (social or non-social), and whether the verbal prompt was an extra-textual comment or question were counterbalanced across each JA episode. The word count of extra-textual talk for JA episodes across the four videos ranged from a mere four to seven words ($M = 4.94$, $SD = 1.050$).

Each video also included two DB episodes. The DB episodes were initiated by the adult reader by directing their gaze to the camera and asking a general question related to the picture book. The questions were not designed to be specific comprehension-based questions about the text, and no gestural points were used. The first DB episode (DB1) occurred in the middle of the book reading, for example with a question such as, "Do you like bubble baths?". The second DB episode (DB2) occurred after the adult reader finished reading the final page of the picture book. This episode involved asking a question, for example, "Do you like pancakes?' in reference to the food item that was the subject of the book title, followed by the adult reader acknowledging "I do". The word count of each DB question ranged from four to seven words. Descriptive characteristics for each picture book video in terms of frequency and duration of presentation, and extra-textual talk during JA and DB episodes are noted in Table 3.3.

Table 3.3

Descriptive Characteristics of Picture Book Videos

Picture book video	Video presentation		Extra textual talk	
	Frequency (%)	Duration	Average WC (*SD*)	Range
If you give a dog a donut	ASD: 14 (25) TYP: 7 (20.6)	3 min, 57 sec	4.9 (1.2)	3-7
If you give a cat a cupcake	ASD: 15 (26.8) TYP: 8 (23.5)	4 min, 31 sec	5.2 (1.3)	3-7
If you give a mouse a brownie	ASD: 15 (26.8) TYP: 10 (29.4)	4 min, 10 sec	5.0 (0.8)	4-6
If you give a pig a pancake	ASD: 12 (21.4) TYP: 9 (26.5)	4 min, 21 sec	4.6 (0.8)	3-6

Note. The frequency (%) of viewing of each video per participant group. The duration of the video. ASD autism spectrum disorder; TYP, neurotypical; WC, word count.

A hired cameraman was responsible for recording, editing and developing the videos. Each video was recorded in the same location on the same day, and as such, all features of the scene (other than the different picture books) remained consistent across each video. Camera angles also remained consistent throughout recordings. The video was edited so that within each JA episode, there were two camera views when the adult reader pointed to the target illustration in the book; the first was with the adult reader and background objects all in view (Figure 3.2), and the second was a close-up view of the book and target illustration being pointed to (Figure 3.4). The close-up view was used to ensure that the participant could clearly see the target illustration within the JA sequence, and, as the task was presented as an eye tracking task, the spatial resolution was large enough to differentiate between the area of interest (AOI) around the target illustration in comparison to other illustrations on the page. The close-up view was followed by the camera zooming back out again to include all scene elements while the adult reader looked back at the camera as part of the final sequence in the joint attention episode. Video editing techniques further ensured standardisation to the greatest extent possible across all four videos.

Figure 3.1

Initiation of JA Episode

Note. Adult reader initiates JA sequence by directing their gaze at viewer and verbalising extra-textual comment or question. JA, joint attention. Areas of Interest (AOIs) include the static objects in each quadrant of the scene, and dynamic AOIs drawn around the book, and face and eyes of the adult reader.

Figure 3.2

Explicit Cuing to Target Illustration During JA Episode

Note. Adult reader directs gaze and points to the target illustration in the picture book within JA episode. JA, joint attention. Dynamic AOIs are adjusted as the reader engages in the story and include the face and eyes, the picture book and target illustration.

Figure 3.3

Engaging in Shared Awareness of Target Illustration During JA Episode

Note. Adult reader redirects gaze to viewer in perceived bid for shared awareness of target illustration during JA episode. JA, joint attention.

Figure 3.4

Close-up View of Target Illustration During JA Episode

Note. Close-up view of adult reader pointing to target illustration during JA episode. JA, joint attention. Area of Interest (AOI) drawn around the target illustration during close-up view.

3.3.3. Baseline Measures

The ADOS-2 was administered to all autistic children, generating calibrated severity scores (CSS) ranging from 1 to 10, for Total, Social Affect (SA) Repetitive and Restrictive Behaviour (RRB) domains, with higher scores indicating greater symptom severity (Gotham et al., 2009). Modules 1 (n = 25), 2 (n = 19) or 3 (n = 11) were administered based on participant age and expressive language level.

To assess non-verbal IQ (NVIQ), participants completed either the Leiter International Performance Scale - Third Edition (Leiter-3; Roid et al., 2013) or the Mullen Scales of Early Learning (MSEL; Mullen, 1995). For the MSEL, developmental quotients (DQs) for the

Visual Reception and Fine Motor subscales were calculated by dividing the age equivalent scores with chronological age and multiplying by 100, and then averaging the two subscales to derive a non-verbal DQ (NVDQ) as a proxy for NVIQ (Hodge et al., 2021; Nevill et al., 2017; Uljarević et al., 2018). A composite variable for NVIQ was then created by incorporating NVDQ scores from the MSEL and the NVIQ scores from the Leiter-R.

To assess receptive language (RL), the Peabody Picture Vocabulary Test – Fourth Edition (PPVT; Dunn and Dunn, 2007) was administered, producing age-normed standard scores (m = 100, SD = 15). As not all participants were administered the PPVT-4, a composite RL variable was created including both the standardised T-scores of the PPVT-4 and RL T-Scores of the MSEL.

As a measure of social functioning, caregivers completed the Social Responsiveness Scale – Second Edition (SRS-2; Constantino & Gruber, 2012), producing T-scores for the domains of Restricted Interests and Repetitive Behaviour (RRB) and Social Communication and Interaction (SCI), which combine to an overall Total Score (Constantino & Gruber, 2012). Total T-scores above 75 indicate severe social deficits, scores between of 66 to 75 are considered moderate, scores of 60 to 65 are considered mild, and scores below 60 indicate no socially challenged behaviour related to ASD (Bruni, 2014).

3.3.4. Eye-Tracking Procedure

Participants entered a dimly lit room with sparse room décor and were given the time they needed to familiarise themselves with the environment. Participants sat on a height adjustable chair fitted with a booster seat, or a regular office chair, depending on their age and height, which was positioned in front of the computer screen. If the participant was distressed, a short, animated film was presented to direct their attention to the screen and interest in the task. Participants were positioned approximately 65 cm away from the 23-inch monitor with a pixel resolution of 1920 x 1080. The scene subtended visual angles of 42.85 x 25.24 degrees.

Eye-tracking data was collected using either a standalone Tobii X120 with a sampling rate of 120Hz and a gaze accuracy of 0.4 degrees (ASD: $n = 7$; TYP: $n = 4$), or an integrated TX300 eye tracker with a sampling rate of 300Hz and equivalent gaze accuracy at 0.4 degrees (ASD: $n = 48$; TYP: $n = 30$) (Tobii Technology, Stockholm, Sweden). Data was aggregated using Tobii Studio Version 3.4.8 (Tobii Technology AB, 2016).

Participants completed a 9-point calibration procedure. Once calibration was completed, participants were told that they would be watching a short movie. One of four videos were randomly presented. During the task administration, the researcher stood next to the participant and if needed, would gently redirect their attention to the screen to encourage task completion. The duration of each video ranged from 3 minutes and 57 seconds to 4 minutes 31 seconds (Mean duration = 4 minutes and 15 seconds, $SD = 14.66$ seconds). A chi-squared test for independence revealed there were no significant differences in the frequencies of which video was presented to participants within each group, $\chi^2 (1,90) = .34$, $p = .91$, $phi = .08$ (Table 3.3).

3.4. Data Analysis

3.4.1. Procedure for Video Overall

An I-VT filter was applied to raw data, using a velocity threshold of 30 degrees/second, a velocity window of 20ms, minimum fixation duration of 100ms and a maximum interpolation of 75ms (Tobii Technology AB, 2016). Areas of Interest (AOIs) with a 40-to-50-pixel margin were drawn around the four quadrants of background objects, whose dimensions remained consistent across all four videos, being static stimuli within the task (Figure 3.1). The subtended angles of background objects were as follows: upper left quadrant = 11.50 x 9.05 degrees, upper right quadrant = 9.30 x 10.41 degrees, lower left quadrant = 11.55 x 9.83 degrees, lower right quadrant = 7.92 x 12.74 degrees. The four quadrants of background objects were grouped to create a *Background Objects (BO)* variable and were considered the non-salient, distractor stimuli of the task.

The dynamic AOIs in the task included the eyes and face of the adult reader, the book, and within JA episodes, around the finger and target illustration in the book (both within the standard and close-up views) (Figures 3.1 to 3.4). Dynamic AOIs were manually adjusted frame by frame to account for the adult reader's movement throughout the videos while including the critical features of the AOI. For example, the AOI for the eyes included a rectangular buffer perimeter extending between the nasal bone and superciliary arch above the eyebrows vertically, and the hairline laterally. To account for spatial noise, a 40–50-pixel perimeter was maintained around dynamic AOIs where possible, so as not to overlap with adjacent AOIs or scene features irrelevant to analyses. For the purposes of data analysis, the two joint attention AOIs (in standard and close-up views) were combined to create a *Joint Attention (JA)* dependent variable (DV). In addition, the *Eyes, Face*, *Book,* and *JA* AOIs were combined to create a *Shared Book Reading (SBR)* DV, reflecting the salient stimuli within the scene. Figures 3.1 – 3.4 display the AOIs drawn for each video.

To account for individual differences in attention to the scene, we adopted an approach used in previous studies (Chawarska et al., 2012; Plesa Skwerer et al., 2019), calculating the ratio of total fixation duration to the scene by dividing total fixation duration to the screen by the recording duration of the task and multiplying by 100 (*Scene*). The *Scene* DV then served as the denominator for calculating the ratio of fixation duration to individual AOIs including the *Face, Eyes*, *Book*, *JA*, and grouped *BO* and *SBR* variables, relative to the *Scene DV*.

To investigate between-group differences, one-way ANOVAs were separately conducted for the DVs of ratio of attention to the *Scene*, *Face*, *Eyes*, *Book*, *BO,* and *SBR* AOIs across the whole video. A mixed-model ANOVA was also conducted with *BO* and *SBR* DVs as the within group variables to examine the distribution of attention to salient and non-salient stimuli of the scene across both groups. Log transformations were applied to the *Eyes, BO*, and *SBR* DVs after exploratory data analysis indicated there were not normally distributed. Subsequent one-way and mixed-model ANOVAs are reported using transformed values, although to ease interpretability across findings, untransformed means and SDs are reported.

3.4.2. Procedure for Joint Attention and Dyadic Bid Episodes

Joint attention episodes were temporally segmented into three discrete segments reflecting the 3-sequenced joint attention process described above. Segment 1 included the duration between the adult reader gazing directly at the camera and initiating an extra-textual verbalization to the viewer until they started to turn their head and avert their gaze to the picture book. Segment 2 was initiated when the adult reader began shifting their head and gaze and pointing to the target illustration in the picture book (i.e., the object of JA), and ended when the adult reader began shifting their head to look back at the camera. Segment 3 included the duration of the adult reader shifting their head and gaze back to the camera whilst maintaining their point on the target illustration and ended when they continued reading the picture book. Eye tracking variables were exported for each joint attention segment and the combination of all segments (labelled JA overall). As the duration of joint attention segments across all videos was not normally distributed, Kruskal-Wallis tests were performed separately on each segment to determine if there were statistically significant differences in the duration of segments across the four videos. Segment 1 (n = 32), χ^2 (3) = .417, p = .937, Segment 2 (n = 32), χ^2 (3) = .658, p = .883 and JA overall (n = 32), χ^2 (3) = 4.034, p = .258, were found to be not significant across all videos, while a statistically significant difference was found for Segment 3 (n = 32), χ^2 (3) = 13.450, p = .004. The durations of each segment and JA overall across the four videos are reported in Table 3.4.

Table 3.4

Duration (ms) of Joint Attention Segments and Episodes Per Video

Picture book video	Mean	*SD*	Min	Max	Range
If you give a dog a donut					
Overall	8211.63	526.49	7236.00	8824.00	1588.00
Segment 1	1792.38	370.61	1411.00	2647.00	1236.00
Segment 2	4216.88	148.43	4058.00	4412.00	354.00
Segment 3	1473.13	360.87	883.00	2118.00	1235.00
If you give a cat a cupcake					
Overall	8358.50	673.83	7677.00	9697.00	2020.00
Segment 1	1868.75	369.92	1415.00	2424.00	1009.00
Segment 2	4141.50	591.30	2829.00	4849.00	2020.00
Segment 3	1590.75	450.88	808.00	2222.00	1414.00
If you give a mouse a brownie					
Overall	8749.00	750.078	7562.00	9887.00	2325.00
Segment 1	1963.00	625.57	1357.00	3102.00	1745.00
Segment 2	3997.25	424.838	3296.00	4459.00	1163.00
Segment 3	2039.75	233.908	1551.00	2327.00	776.00
If you give a pig a pancake					
Overall	8571.63	436.578	8163.00	9184.00	1021.00
Segment 1	1683.88	144.508	1428.00	1837.00	409.00
Segment 2	4056.00	297.53	3469.00	4490.00	1021.00
Segment 3	2091.88	373.95	1632.00	2653.00	1021.00

The approach used in the analysis of gaze behaviour across JA episodes, involved calculating the proportion of fixation duration to each AOI [*Eyes*, *Face*, *Book*, *JA*, *BO,* and *SBR*] by dividing by the total fixation duration to the screen and multiplying by 100. The total fixation to the screen variable was deemed a more suitable denominator to account for individual differences as the recording duration of each segment within each episode varied within and across each video. Consistent with the analytic approach to the overall video, one-way ANOVAs for each individual AOI, and a mixed-model ANOVA with *BO* and *SBR* as the within subject variables were conducted on JA overall. As with the overall video, log transformations were performed on DVs that were not normally distributed.

As one of the goals of the study was to analyse differences in gaze behaviour throughout the sequence of joint attention, group differences in attention to specific AOIs within JA segments were examined. Separate one-way ANOVAs were conducted to investigate group differences in the *Face, Eyes, BO,* and *SBR* DVs in Segment 1; the *Face, Book, JA* and *SBR* DVs in Segment 2, and the *Face*, *Eyes, Book*, *JA, BO and SBR* DVs in Segment 3. In addition, Pearson's correlations were conducted to explore the relationships between specific salient and non-salient DVs across different segments to demonstrate whether attention to specific AOIs in the initial stages of JA were related to attention to relevant AOIs in later stages of the JA sequence. In this regard, within group correlations in attention to the *Face*, *Eyes, BO* and *SBR* AOIs across Segments 1 and 3, and between attention to the *Face* and *Eyes* AOIs in Segment 1 and Book and JA AOIs in Segment 2, were explored.

Dyadic bid (DB) episodes included the time when the adult reader initiated an extra-textual question to the participant while gazing directly at the camera until her gaze averted to the book. The first dyadic bid in each video (labelled DB1) included a general question which was interweaved in a natural manner within bids for joint attention. The second dyadic bid (DB2) was a general question directed to the viewer at the end of the book reading of each video. Graphical analyses revealed similar durations of DB1 across all four videos, while DB2 in video 4 was of greater duration compared to the other videos. The average duration (ms) for DB1 was $M = 2551.50$, $SD = 264.78$, Range = 2245 – 2823, and for DB2 was $M = 3491.00$, $SD = 547.73$, Range = 3030 – 4285. Consistent with the analytic approach for the overall video and JA overall, one-way ANOVAs were conducted on the salient AOIs of *Face* and

Eyes for each dyadic bid. Log transformed values for the *Eyes* DV were used and reported in subsequent analyses.

3.4.3. Procedure for Exploring Associations with Clinical Characteristics

Associations between attention DVs and relevant clinical characteristics were explored in both cohorts across the video overall, JA overall, and DB episodes using Pearson's product-moment correlations. For both groups, correlations between attention DVs and NVIQ, RL and SRS-2 T-Scores were conducted. In the ASD group, correlations between attention DVs and ADOS-2 CSS scores were also explored. Due to sample size limitations and the exploratory nature of these associations, adjustments for multiple comparisons were not included in analyses.

3.4.4. Preliminary Analysis

Preliminary analysis of RL and NVIQ scores indicated significant differences between ASD and TYP groups (RL: t (50) = 4.836, $p < .001$; NVIQ: t (73) = 5.783, $p < .001$). The RL scores of the ASD group were significantly lower than for the TYP group (ASD: n = 38, M = 69.08, SD = 36.60; TYP: n = 14, M = 117.57, SD = 11.99). Similarly, NVIQ scores were lower for ASD compared to TYP groups (ASD: n = 49, M = 93.57, SD = 18.04; TYP: n = 26, M = 116.54, SD = 12.59). As the between group differences in these clinical variables are considered to reflect common co-occurring conditions in ASD (Americal Psychiatric Organisation, 2013; Lord et al., 2020), an *a priori* decision was made to exclude them as covariates in between group analyses of attention DVs (Dennis, 2011; Schneider, 2015).

Consistent with previous studies (Chawarska et al., 2012; Harrop et al., 2018b; Plesa Skwerer et al., 2019), the quality of gaze data was set to 20% in consideration of the inclusive approach to include autistic children with varying cognitive and language profiles. The gaze data of one TYP participant and nine ASD participants were excluded from analysis due to low quality data. One TYP participant and five ASD participants did not complete the task by watching the entire video. As subsequent analyses conducted with and without these participants revealed no significant differences in results, results are reported inclusive of their data. To explore potential between group differences in task completion, a Mann-Whitney U Test was conducted on the recording duration for each group, indicating no significant differences $U = 873.00$, $z = -.657$, $p = .511$.

3.5. Results

3.5.1. Patterns of Attention During the Video Overall

There were statistically significant between group differences in attention to the *Scene, Face, BO* and *SBR* AOIs (all $p < .001$). Compared to the TYP group, the ratio of attention directed to the *Scene, Face*, and *SBR* AOIs was significantly reduced in the ASD group (Scene: $M_{diff} = 19.80$, $SE = 3.80$; Face: $M_{diff} = 25.51$, $SE = 5.38$; SBR: $M_{diff} = 45.44$, $SE = 8.89$). In contrast, the ratio of attention directed to the *BO* AOI was significantly higher in the ASD compared to the TYP group ($M_{diff} = 21.34$, $SE = 4.33$). There were no significant differences in attention to the *Eyes* or *Book* AOIs. Table 3.5. details the means (SD) and results of one-way ANOVAs for each DV. Figure 3.5. illustrates group differences in the proportion of attention to individual AOIs in the video overall.

Table 3.5

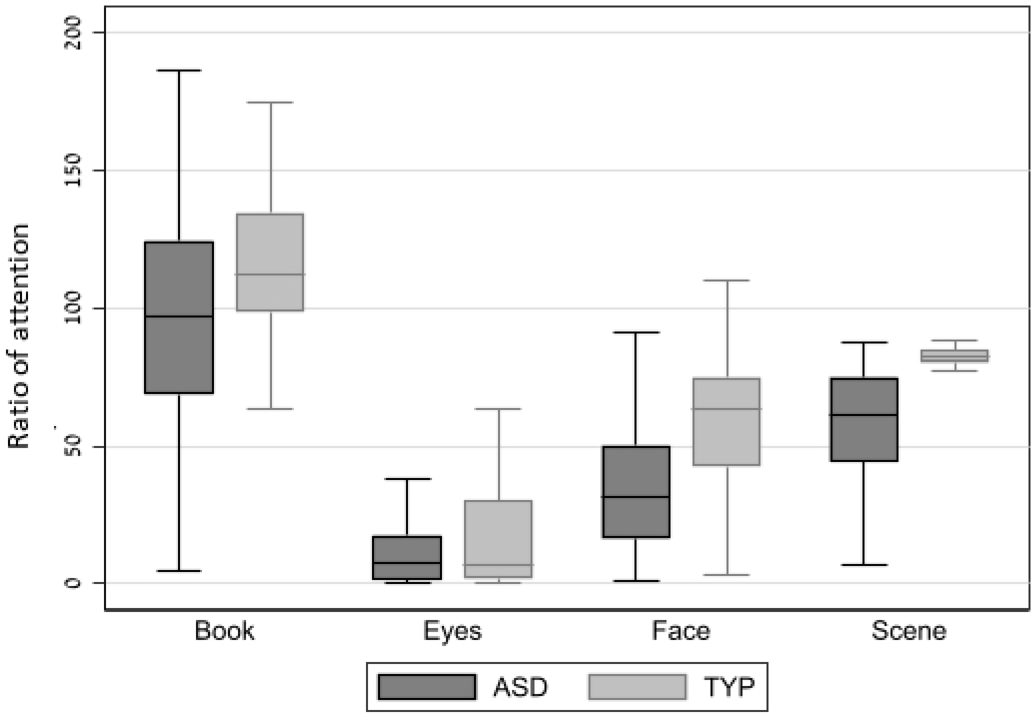
Means (SD) and Group Differences in Attention to the Scene and the Ratio of Attention to Individual and Grouped AOIs (Relative to the Scene) in the Video Overall

AOIs	ASD	TYP				
	M (SD)	*M (SD)*	*df*	*F*	*p*	η_p^2
Scene	59.11 (19.24)	78.88 (14.13)	(1,88)	27.000	< .001	.235
Face	34.83 (23.90)	60.34 (25.80)	(1,88)	22.523	< .001	.206
Eyes	12.33 (15.01)	18.34 (23.61)	(1,77)	.255	.170	.024
Book	98.48 (39.50)	113.77 (31.02)	(1,89)	3.699	.058	.040
BO	29.28 (24.62)	7.94 (6.65)	(1,87)	34.635[Ɨ]	< .001	.285
SBR	146.05 (45.99)	191.49 (30.54)	(1,88)	32.425	< .001	.269

Note. AOIs, areas of interest; ASD; autism spectrum disorder; BO, Background Objects; SBR, Shared Book Reading; TYP, neurotypical.

Figure 3.5

Attention to the Scene and Ratio of Attention to Individual and Grouped AOIs (Relative to the Scene) in the Video Overall

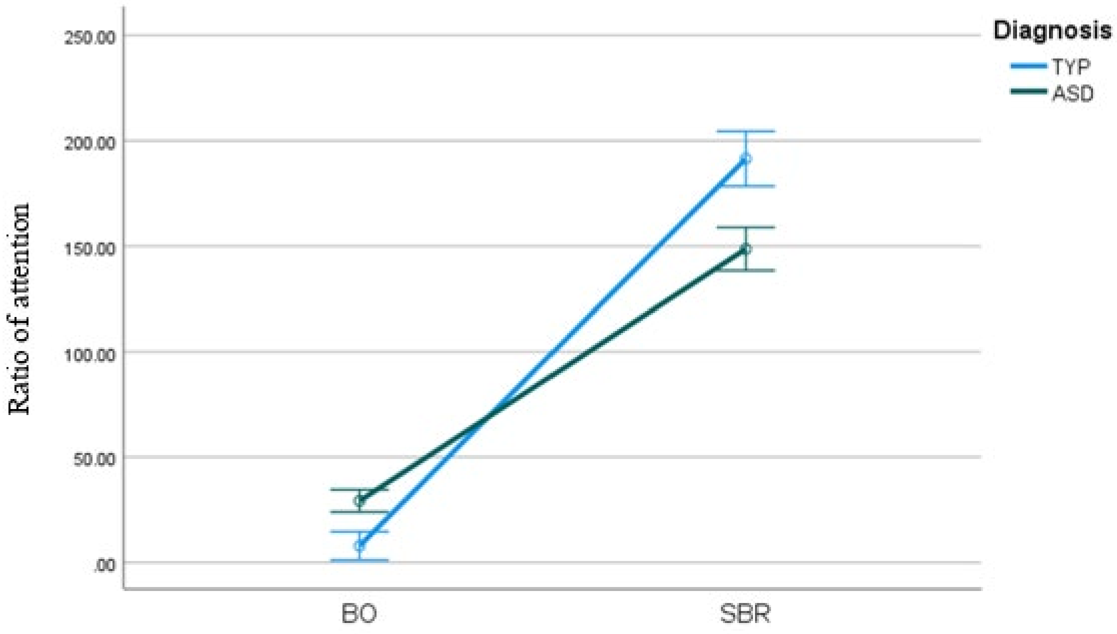


Note. Distribution of the ratio of fixation duration to individual and grouped AOIs in the video overall relative to the fixation duration to the *Scene*. AOIs, areas of interest; ASD, autism spectrum disorder; TYP, neurotypical.

A mixed-model ANOVA with *BO* and *SBR* as the within-subject variables and diagnosis as the between-subjects variable indicated a significant interaction effect, F (1,87) = 23.373, $p < .001$, $\eta_p^2 = .212$, and significant main effects for condition, F (1,87) = 1621.813, $p < .001$, $\eta_p^2 = .949$, and diagnostic group, F (1,87) = 38.146, $p < .001$, $\eta_p^2 = .305$. The TYP group allocated greater attention to the salient *SBR* stimuli, while the ASD group allocated greater attention to the distractor *BO* stimuli (Figure 3.6). Pairwise comparisons revealed that both groups allocated greater attention to *SBR* AOIs ($M_{diff} = 151.443$, $SE = 5.562$), and TYP children allocated greater attention across both conditions compared to ASD children ($M_{diff} = 10.764$, $SE = 3.617$).

Figure 3.6

Ratio of Attention to Salient and Non-Salient Stimuli (Relative to the Scene) in the Video Overall



Note. Estimated marginal means (with standard error bars) for the ratio of fixation duration to salient SBR and non-salient BO AOIs (relative to the *Scene*)in the video overall for ASD and TYP groups. ASD, autism spectrum disorder; AOIs, areas of interest; BO, background objects; SBR shared book reading; TYP neurotypical.

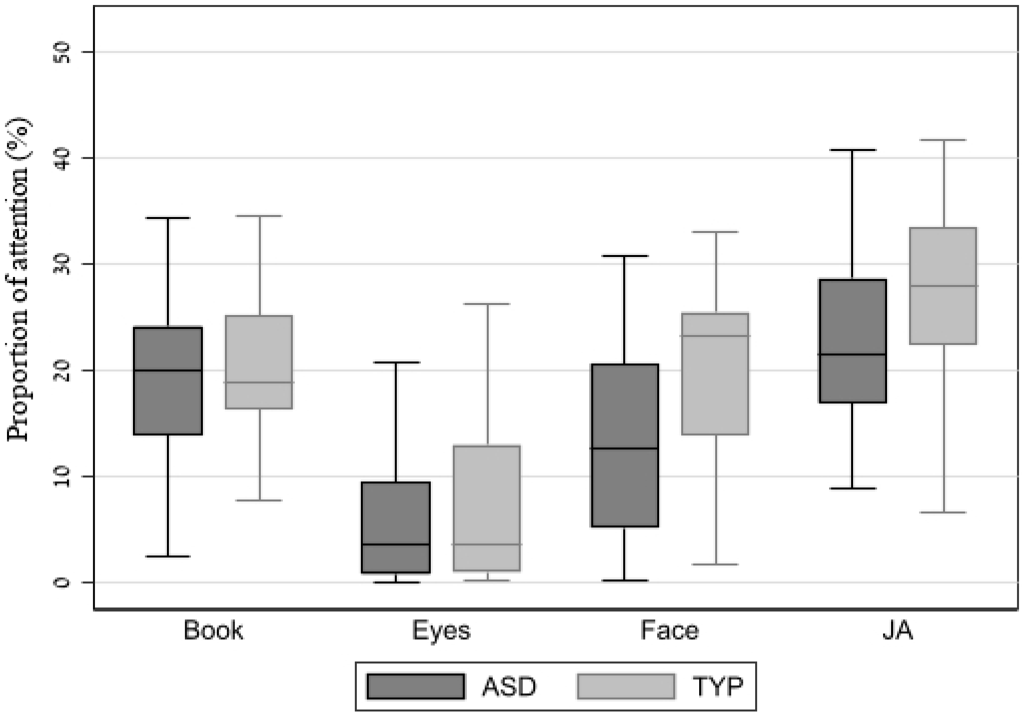
3.5.2. Patterns of Attention During JA Episodes

3.5.2.1. Attention During JA Overall

The next set of analyses investigated the proportion of attention to salient and non-salient stimuli across JA overall. The means (*SD*) and results of one-way ANOVAs for each DV is detailed in Table 3.6. There were statistically significant group differences in attention to the *Face*, *JA*, *SBR* and *BO* AOIs (all $p < .001$). Compared to the TYP group, the ASD group spent significantly less time attending to the salient *Face, JA* and *SBR* AOIs (Face: $M_{diff} = 6.945$, $SE = 1.884$; JA: $M_{diff} = 6.083$, $SE = 1.731$; SBR: $M_{diff} = 13.251$, $SE = 2.740$) and more time attending to the non-salient *BO* AOIs (BO: M_{diff} = 5.514, *SE* = 1.242). There were no significant between group differences in attention to the *Eyes* or *Book* AOIs. Figure 3.7. displays mean differences in the proportion of attention directed to individual AOIs during JA Overall.

Figure 3.7

Proportion of Attention to Individual AOIs During JA Overall

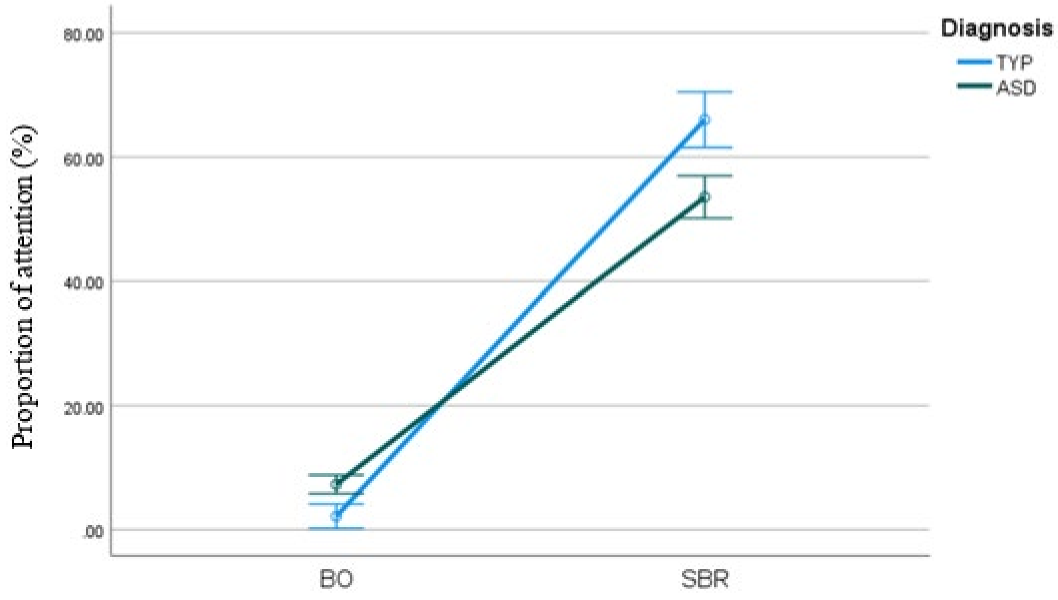


Note. Distribution of proportion of attention (expressed as a percentage) to individual AOIs during JA episodes overall. AOIs, areas of interest; ASD, autism spectrum disorder; JA, joint attention; TYP, neurotypical.

Consistent with the approach to the overall video, the between-group distribution of attention to *BO* and *SBR* DVs in JA overall was analysed. Results revealed a significant interaction effect between *BO* and *SBR* DVs and diagnostic group, Wilks' lambda = .771, $F(1,82) = 24.366$, $p < .001$. The ASD group exhibited greater attention to *BO* AOIs while the TYP group spent more time attending to *SBR* AOIs (Figure 3.8.). Significant main effects for the within-subject *BO* and *SBR* DVs, F (1,82) = 693.181, $p < .001$, $\eta_p^2 = .894$ and diagnostic group, F (1,82) = 13.576, $p < .001$, $\eta_p^2 = .142$ were also found, indicating that both groups directed more attention to *SBR* compared to *BO* AOIs ($M_{diff} = 55.070$, $SE = 1.824$), while the TYP group directed more attention across both types of AOIs compared to the ASD group ($M_{diff} = 3.657$, $SE = 1.203$).

Figure 3.8

Proportion of Attention to Salient and Non-Salient Stimuli During JA Overall



Note. Estimated marginal means (with standard error bars) for the proportion of fixation duration (expressed as a percentage) to salient SBR and non-salient BO AOIs in JA overall for ASD and TYP groups. ASD, autism spectrum disorder; AOIs, areas of interest; BO, background objects; JA, joint attention; SBR shared book reading; TYP neurotypical.

3.5.2.2. Attention Within Each Segment

As one of the aims of the study was to investigate differences in attention within the temporal sequence of JA, between group differences in the proportion of attention directed to specific AOIs within each segment of JA episodes were analysed.

Segment 1 – Initiation of JA Episode

Analyses revealed significant group differences in attention to the *Face*, *Eyes, BO*, and *SBR* AOIs. In relation to the TYP group, the ASD group displayed reduced attention to the *Face* and *SBR* AOIs (Face: M_{diff} = 10.203, *SE* = 4.614; SBR: M_{diff} = 13.496, *SE* = 4.100). Inversely, the ASD group exhibited greater attention to the *BO* AOIs compared to the TYP group (M_{diff} = 9.665, *SE* = 3.704). As a log transformation of the *Eyes* DV did not improve normality, a Mann-Whitney U test was performed revealing no significant differences between ASD and TYP groups, *U* = 461.00, *z* = -.347, *p* = .728.

Segment 2 – Explicit cuing to Target Illustration

During this segment, of specific interest was group differences in attention allocated to the *JA* AOI, in addition to group differences in attention to the *Face, Book*, and *SBR* AOIs. The ASD group displayed reduced attention to the *JA* and *SBR* AOIs (JA: M_{diff} = 10.762, *SE* = 3.062; SBR: M_{diff} = 10.762, *SE* = 3.062), compared to the TYP group. There were no significant differences in attention to the *Face* or *Book* AOIs.

Segment 3 – Engaging in Shared Awareness of Target Illustration

In the final segment of the JA sequence, group differences in the proportion of attention directed to the *Face*, *Eyes*, *Book, JA, SBR* and *BO* AOIs were examined. The ASD group spent significantly less time looking to the salient *Face*, *JA*, and *SBR* AOIs (Face: M_{diff} = 11.248, *SE* = 3.584; JA: M_{diff}= 5.287, *SE* = 2.516; SBR: M_{diff} = 17.064, *SE* = 3.407), while spending more time looking to the non-salient *BO* AOI (M_{diff} = 8.254, *SE* = 1.985), compared to the TYP group. There were no significant differences in attention to the *Eyes* or *Book* AOIs. Table 3.6 details the means (SD) and results of one-way ANOVAs for each DV with each segment.

Table 3.6

Means (SD) and Group Differences in the Proportion of Attention to AOIs during JA Episodes

AOIs	ASD	TYP				
	M (SD)	*M (SD)*	*df*	*F*	*p*	η_p^2
JA Overall						
Face	13.98 (8.95)	20.92 (7.95)	(1,85)	13.590	< .001	.138
Eyes	6.08 (6.88)	7.51 (7.56)	(1,67)	.299	.530	.006
Book	20.06 (8.48)	21.58 (6.88)	(1,67)	.665	.417	.010
JA	22.26 (7.32)	28.34 (8.85)	(1,87)	12.347	< .001	.124
BO	7.31 (6.76)	2.15 (1.82)	(1,82)	21.027	< .001	.204
SBR	53.14 (13.80)	66.39 (10.25)	(1,87)	20.631	< .001	.192
Segment 1						
Face	33.89 (21.69)	44.10 (18.89)	(1,80)	4.891	.030	.058
Eyes	17.23 (17.29)	17.29 (15.70)	-	-	.728 [Ɨ]	-
BO	16.27 (14.35)	6.60 (5.60)	(1,57)	4.817	.032	.078
SBR	68.03 (20.55)	81.52 (15.36)	(1,86)	11.696	< .001	.120
Segment 2						
Face	2.26 (2.79)	1.52 (1.13)	(1, 65)	1.844	.179	.028
Book	3.46 (2.29)	2.68 (7.96)	(1, 85)	2.651	.107	.031
JA	39.89 (13.84)	50.66 (14.36)	(1,87)	12.352	<.001	.124
SBR	43.97 (14.07)	53.67 (14.00)	(1,87)	10.023	.002	.103
Segment 3						
Face	20.83 (16.75)	32.08 (15.30)	(1,83)	9.852	.002	.106
Eyes	9.30 (10.19)	13.79 (12.65)	(1,54)	1.262	.267	.029
Book	35.41 (16.93)	40.04 (14.79)	(1,86)	1.713	.194	.020
JA	13.36 (10.72)	18.64 (11.58)	(1,80)	7.409	.008	.085
SBR	56.38 (17.80)	73.45 (11.20)	(1,87)	25.092	< .001	.224
BO	13.09 (9.98)	4.84 (3.42)	(1,76)	23.361	< .001	.235

Note. AOIs, areas of interest; ASD, autism spectrum disorder; BO, background objects; JA, joint attention; SBR, shared book reading; TYP, neurotypical.

[Ɨ] U-value of Mann-Whitney U test performed as log transformations did not improve normality

3.5.2.3. Attention Across Segments

Bivariate correlations were conducted to explore the associations in attention to specific AOIs between different segments. For both ASD and TYP group, there were significant positive correlations in attention to the *Face* AOI between Segments 1 and 3 (TYP: $r = .661, p = .000$; ASD: $r = .595, p = .000$). These results suggested that for both autistic and neurotypical children, there was a maintenance of attention to the adult reader's face throughout the JA episode. Similarly, for both groups there were significant positive correlations between Segments 1 and 3 in attention to the *Eyes* (TYP: $r = .754, p < .001$; ASD: $r = .742, p = .000$), and in attention to *SBR* stimuli (TYP: $r = .692, p = .000$; ASD: $r = .551, p = .000$). A significant positive correlation in attention to the *BO* stimuli ($r = .555, p = .000$) between Segments 1 and 3 was also evident for the ASD group only. This association also provided an indication that autistic children who directed greater attention to the distractor BO stimuli as the JA episode was initiated were more likely to maintain their attention on these stimuli throughout the sequence. In addition, for the ASD group, there was a significant positive correlation between attention to the *Face* in Segment 1 and attention to the *JA* ($r = .342, p = .017$) and *SBR* ($r = .354, p = .009$) AOIs in Segment 2. These results suggested that autistic children who exhibited greater initial allocation of attention to salient social cues were subsequently more likely to shift their attention to the target illustration. These correlations were not significant for the TYP group.

3.5.3. Proportion of Attention During Dyadic Bid Episodes

During DB episodes, group differences in the proportion of attention directed to the *Eyes* and *Face* AOIs were examined. Results revealed significant group differences in attention to the *Face* AOIs in both DB episodes ($p < .001$). The ASD group spent significantly less time attending to the *Face* AOIs in both DB1and DB2 episodes, compared to the TYP group. There were no significant differences in attention to the *Eyes* AOI for either episode (Table 3.7).

Table 3.7

Means (SD) and Group Differences in the Proportion of Attention to Salient AOIs During DB Episodes

AOIs	ASD	TYP				
	M (SD)	***M (SD)***	***df***	***F***	***p***	η_p^2
DB1						
Face	47.43 (30.78)	76.54 (20.97)	(1,55)	17.873	< .001	.245
Eyes	47.23 (17.90)	41.80 (30.20)	(1,26)	.322	.576	.012
DB2						
Face	50.42 (24.40)	76.71 (20.43)	(1,62)	21.838	< .001	.260
Eyes	27.55 (25.65)	41.72 (32.06)	(1,31)	.967	.222	.030

Note. AOI, areas of interest; ASD, autism spectrum disorder; DB1, dyadic bid episode 1; DB2, dyadic bid episode 2; TYP, neurotypical.

3.5.4. Associations Between Attention and Clinical Characteristics

3.5.4.1. Receptive language (RL)

In the TYP group, there was a significant negative correlation between RL and attention to the *Face* AOI ($p = .040$), and a significant positive correlation with attention to the *Book* AOI ($p = .030$), for the video overall. These results indicated that better RL skills were associated with reduced attention to the face and greater attention to the picture book. In JA overall, only attention to the *Book* AOI was positively correlated with RL.

In the ASD group, significant positive correlations were evident between RL and attention to the *Book* (p = .004) and *SBR* (p = .029) AOIs in the video overall. A significant positive correlation with attention to the *Book AOI* was also seen in JA overall (p = .045). Strong negative correlations between RL and attention to *BO* AOIs were demonstrated in the video overall (p = .029) and JA overall (p =.006), respectively. These results suggested that autistic children with better RL skills allocated greater attention to the book and SBR stimuli and less attention to distractor stimuli. There were no significant associations between RL and attention to the *Face* or *Eyes* AOIs in DB episodes for either group.

3.5.4.2. Non-Verbal IQ (NVIQ)

In the TYP group, NVIQ was negatively associated with attention to the *Face* AOI in the video overall (p = .003), and JA overall (p =.021), respectively. In contrast, positive correlations between NVIQ and attention to the *Book* AOI were shown in the video overall (p = .022) and JA overall (p = .015). Significant negative associations were seen between NVIQ and attention to the *Face* AOI in DB1 (p = .043) and DB2 (p = .010) for the TYP but not the ASD group. Similar to the correlations with RL skills, higher NVIQ was found to be related to reduced attention to the face and greater attention to the picture book in neurotypical children.

In the ASD group, strong negative correlations between NVIQ and attention to distractor *BO* AOIs were shown in the video overall and JA overall ($p < .001$), while positive correlations were evident with *SBR* AOIs both in the video overall (p = .009) and JA overall (p =.025). A positive association between NVIQ and attention to the *Book* AOI (p = .013) was also seen in the video overall only. Attention to the *Eyes* AOI was not related to NVIQ for either group across any condition. Taken together, results indicate that in autistic children, higher NVIQ was associated with greater attention to salient *SBR* stimuli and reduced attention to distractor *BO* stimuli. Pearson's *r* correlations between relevant attention AOIs, RL and NVIQ are noted in Table 3.8.

Table 3.8

Pearson's Correlations Between Attention, RL and NVIQ Scores

AOIs	Receptive Language		NVIQ	
	TYP	ASD	TYP	ASD
Video Overall				
Scene	-.096	.226	-.188	.206
Face	-.554*	-.051	-.562*	.154
Eyes	-.254	-.004	-.382	.131
Book	.579*	.460*	.448*	.351*
BO	-.089	-.535**	-.247	-.632**
SBR	.270	.354*	.019	.369*
JA Overall				
Face	-.414	.153	-.451*	.224
Eyes	-.109	.099	-.342	.109
Book	.642*	.336*	.471*	.236
JA	.369	-.061	.238	.109
BO	-.511	-.446*	-.289	-.525**
SBR	.423	.214	.044	.324*
DB1				
Face	.001	-.074	-.426*	.131
Eyes	-.036	.092	-.317	-.184
DB2				
Face	-.456	.356	-.514*	.351
Eyes	-.213	-.129	-.183	.311

Note. AOIs, areas of interest; ASD, autism spectrum disorder; BO, background objects; DB 1, dyadic bid episode 1; DB 2, dyadic bid episode 2; JA; joint attention; NVIQ, non-verbal IQ; SBR, shared book reading; TYP, neurotypical

* $p < .05$, ** $p < .001$

3.5.4.3. Social Functioning

In the video overall, there were no significant correlations between SRS-2 SCI, RRB or Total T-scores and attention DVs for either group. Across JA overall, one significant negative correlation between the *Joint Attention* AOI and RRB T-scores ($p = .027$) was found in the ASD group only, indicating greater attention to the target object was associated with less severe RRB behaviours. There were no significant correlations between attention DVs and SRS-2 T-scores across DB episodes. Pearson's *r* correlations between attention and SRS-2 T-Scores are noted in Table 3.9.

Table 3.9

Pearson's Correlations Between Attention and SRS-2 T-Scores

AOIs	SCI		RRB		Total	
	TYP	ASD	TYP	ASD	TYP	ASD
Video Overall						
Scene	.139	-.241	-.007	-.192	.114	-.237
Face	.114	.071	-.136	-.139	.044	.033
Eyes	-.062	.084	-.036	-.075	-.056	.060
Book	-.191	-.176	.080	-.120	-.129	-.171
BO	.141	.188	.030	.071	.140	.165
SBR	-.093	-.088	.000	-.179	-.079	-.109
JA Overall						
Face	.093	.026	-.253	-.095	.003	.007
Eyes	-.212	.084	-.119	-.039	-.195	.066
Book	-.126	-.131	.144	-.022	-.053	-.118
JA	.016	-.166	.227	-.298*	.080	-.207
BO	-.045	.198	-.076	.088	-.066	.189
SBR	-.008	-.138	.020	-.231	.008	-.160
DB1						
Face	.115	.067	.172	-.121	.137	.026
Eyes	.028	.349	-.026	.318	.029	.382

DB2						
Face	.252	-.042	.162	-.091	.233	-.050
Eyes	-.080	.006	.038	-.116	-.040	-.038

Note. AOIs, areas of interest; ASD, autism spectrum disorder; BO, background objects; DB 1, dyadic bid episode 1; DB 2 , dyadic bid episode 2; JA, joint attention; SBR, shared book reading; SCI, social communication and interaction; SRS-2; social responsiveness scale – second edition; TYP, neurotypical.

* $p < .05$

3.5.4.4. Autism Severity

In the video overall, significant negative associations were evident between attention to the *Scene* and ADOS-2 RRB CSS ($p = .023$), and between attention to *SBR* AOIs and Total CSS ($p = .025$). Conversely, there were significant positive correlations between attention to *BO* AOIs and Total CSS ($p = .028$) and RRB CSS ($p = .004$). Overall, these results demonstrated that greater attention to the SBR task and the salient stimuli within were related to a lower severity of autism symptoms, whereas greater attention to distractor stimuli was associated with a higher severity of symptoms. There were no significant correlations between ADOS-2 CSS and AOIs within JA Overall or DB episodes. Pearson's *r* correlations between attention to AOIs and ADOS-2 CSS in the video overall and within JA Overall and DB episodes are detailed in Table 3.10.

Table 3.10

Pearson's Correlations Between Attention and ADOS-2 CSS

AOIs	SA	RRB	Total
Video Overall			
Scene	-.109	-.306*	-.196
Face	-.134*	-.150	-.196
Eyes	.022	-.234	-.055
Book	-.195	-.194	-.240
BO	.172	.385*	.298
SBR	-.230	-.248	-.301*
JA Overall			
Face	-.017	-.004	-.009
Eyes	.123	-.162	.055
Book	-.160	-.218	-.238
JA	-.093	-.106	-.137
BO	.148	.185	.208
SBR	-.153	-.210	-.218
DB1			
Face	.033	.052	.124
Eyes	.330	-.416	.190
DB2			
Face	.135	-.270	-.053
Eyes	-.241	-.183	-.238

Note. AOIs, areas of interest; ADOS-2, autism diagnostic observation schedule – 2nd edition; ASD, autism spectrum disorder; BO, background objects; CSS, calibrated severity scores; ; DB1, dyadic bid episode 1; DB2 , dyadic bid episode 2; JA, joint attention; SBR, shared book reading; RRB, restricted and repetitive behaviours; SA, social affect.

* $p < .05$

3.6. Discussion

The purpose of this study was to investigate differences in attentional patterns between autistic and neurotypical young children using a naturalistic SBR task. To do this, a novel SBR task for use in eye-tracking studies was developed. A secondary goal was to explore how these attentional patterns related to important clinical characteristics of child development and autism. The main findings of the study were that compared to neurotypical children, autistic children spent significantly less time attending to the scene in general and the salient elements within the scene, including the adult reader's face and grouped SBR stimuli. Conversely, they spent significantly more time attending to background distractor stimuli.

These results pertaining to attention patterns were repeated across JA episodes, with autistic children directing less of their attention to salient stimuli including the target object in the picture book, in comparison with their neurotypical peers. Interestingly, when autistic children did attend to salient stimuli in the initial stage of JA, they were more likely to attend to the target object and salient SBR stimuli in later stages. On the other hand, greater attention to distractor stimuli carried through the JA sequence and was related to reduced attention to salient stimuli for autistic children. Greater attention to the SBR activity was associated with reduced severity of autism symptoms overall and in relation to social communication symptoms, while greater attention to the distractor stimuli was associated with heightened restrictive and repetitive behaviours. Finally, this study provided some evidence that attentional patterns during the SBR activity were associated with RL and NVIQ. Overall, the results support the use of SBR as an ecologically valid and developmentally appropriate paradigm for understanding the attentional patterns of autistic and neurotypical children and associated developmental outcomes.

In support of the first hypothesis, the proportion of attention directed to the scene, face of the adult reader, and salient SBR stimuli was reduced in autistic children, who also directed more attention to background distractor stimuli. A trend was also found for attention directed to the book, suggesting autistic children spent less time attending to this salient feature of the task. These results are consistent with previous eye-tracking studies employing dynamic paradigms, demonstrating that autistic children exhibit reduced gaze behaviours to salient social components of the scene, while increasing their attention towards irrelevant objects in the background (Chawarska et al., 2012; Franchini et al., 2017; Klin et al., 2002; Rice et al., 2012). These atypicalities in gaze behaviour have been suggested to result in reduced opportunities to learn from social interactions and environmental cues that are instrumental in the development of social, cognitive and language skills across childhood. Moreover, they have also been found to be associated with longer term outcomes including lower academic achievement and adaptive functioning (Brooks & Meltzoff, 2015; Tillmann et al., 2019; van Rijn et al., 2019; Zaidman-Zait et al., 2020).

The results of this study also serve to complement other studies reporting reduced engagement in books and reading in autistic children. For example, Bean et al. (2020) reported that in an educational setting, autistic preschoolers displayed reduced engagement in books compared to their neurotypical and language-delayed peers, and this was related to their skills in print knowledge and phonological awareness. In a separate study, greater print knowledge was associated with increased interest in books and more frequent shared reading practices in the homes of autistic children (Dynia et al., 2014). While the results of these studies, as well as those of the current study are based on cross-sectional data, they do suggest that the attentional patterns exhibited by autistic children during SBR may be predictive of longer term literacy and behavioural outcomes including self-esteem and motivation, school adjustment and academic performance (Baixauli et al., 2021; Hayes et al., 2018; Zaidman-Zait et al., 2020).

The results also showed that across JA episodes, autistic children spent significantly less time attending to the salient aspects of the scene, including the target illustration in the book, the face of the adult reader, and the grouped SBR activity. Additionally, they spent more time attending to the background objects. These results replicate the gaze patterns observed in the overall video and provide evidence supportive of the second hypothesis, that predicted reduced attention to salient stimuli, and increased attention to non-salient components of the task. In this regard, reduced joint attention behaviours, which characteristically include reduced attention to the face and target object, have been found across several eye-tracking studies in autistic children (Chawarska et al., 2012; Cilia et al., 2020; Franchini et al., 2017; Gulsrud et al., 2014; Ishizaki et al., 2021; Korhonen et al., 2014; Swanson & Siller, 2013), and have been proposed as an important behavioural phenotype of ASD (Charman, 2003; Korhonen et al., 2014; Mundy, 2009).

While there are several eye-tracking studies reporting on group differences in attention to face and target stimuli within a 'joint attention' paradigm as described above, there has been limited research investigating how gaze behaviour may vary throughout the triadic temporal sequence of JA. In the current study, when analysing gaze behaviour across JA segments, autistic children consistently allocated less of their attention to salient stimuli than their neurotypical peers. This was evident when autistic children spent less time attending to the face of the adult reader whilst being prompted to engage in joint attention using an extra-textual comment or question. Similarly, they spent less time attending to the target object when the adult reader gesturally cued their attention to the target illustration. Following on from this cue, autistic children also exhibited less attention to the reader's face when they redirected their gaze to the participant in a perceived attempt to communicate shared understanding. Interestingly, correlations suggested that autistic children who showed initial attention to salient cues, continued to show attention to these cues throughout the JA sequence.

In contrast, greater engagement with distractor stimuli initially was associated with greater perseveration in attention to those stimuli and reduced attention to more salient features during JA. In general, these relationships were not found in the neurotypical cohort. Taken together, the results of the study suggest that autistic children exhibited reduced attention to social and salient aspects of this SBR activity compared to their neurotypical peers, and this atypical gaze behaviour was evident temporally throughout the JA sequence.

Operationalisation of the temporal sequence of JA is often missing in eye tracking studies. Only one study has been identified to methodologically investigate the process of joint attention in a temporally sequenced manner. In that study, Wang and colleagues (2020) employed a computerized task of an avatar face directing its gaze to a fruit or vegetable object image on either side of the face in response to the autistic participants being asked to attend to their preferred image. Correlational analyses found no significant associations between attention to the eyes and subsequent attention to the object (Wang et al., 2020). Understandably, one significant limitation emanating from this study as well as other studies reporting on joint attention behaviours in autistic children, is that results are based on the use of unnaturalistic dynamic task paradigms (Cilia et al., 2019; Franchini et al., 2017; Muratori et al., 2019; Wang et al., 2020), thus challenging the interpretation or generalisability of results to real-life joint attention behaviours. As discussed by the authors themselves, as well as others, issues of ecological validity may have a significant influence on results, as well as interpretation (Kwon et al., 2019; Wang et al., 2020).

The results of the current study also found that autistic children displayed reduced attention to the face during bids for dyadic interaction, compared to their neurotypical peers, however this difference did not extend to attention to the eyes. Previous studies reporting on social attention patterns in dyadic bid conditions have also reported mixed results in attention to the face; and no information on attention to the eyes specifically (Chawarska et al., 2012;

Kaliukhovich et al., 2021; Wang et al., 2018). Thus, the results only provide partial support for the third hypothesis. Nevertheless, they do provide an indication as to the direction and nature of the relationship, for which little evidence exists. The results of this study garnered consistent evidence of reduced attention to the face across the video overall and during episodes of joint attention and dyadic interaction, supporting broad literature findings of reduced engagement with social cues in autistic cohorts across childhood (Frazier et al., 2017; Wood-Downie et al., 2020).

Throughout the task, there were no statistically significant group differences in attention to the eyes. These results were not surprising given that previous research has found significant variability with respect to gaze to eyes in autistic children (Chita-Tegmark, 2016a; Congiu et al., 2016; Kwon et al., 2019; Nuske et al., 2015). However, since attention to the eyes of the adult reader tended toward the hypothesized direction in the vide overall, some possible explanations should be considered. Firstly, the standard deviations in the eye DVs for both groups were quite large. Potentially this is reflective of the natural inter-individual variability in attention patterns reported across neurotypical and autistic cohorts (Hayes & Henderson, 2018; Peterson et al., 2016). Secondly, the adult reader directed their eyes to the book for a large portion of the video's duration, leading to a smaller AOI around the eyes when their gaze was averted compared to when gaze was direct, and a much smaller AOI compared to other AOIs in the scene. Therefore, it is possible that the eye tracker may have been insensitive in collecting data on participants' eye movements across the dynamic resizing of this AOI which was designed to mimic real-world conditions. Whilst only a possible explanation, future research should consider such factors when investigating these attentional patterns in similar types of tasks.

The final aim of this study was to explore the relationship between attention during the SBR task and clinical characteristics of autistic children. The results of this study supported the existence of salient correlations between gaze behaviour and key characteristics such as non-verbal IQ, receptive language, and autism severity. The study found that for autistic children with higher non-verbal IQ and receptive language scores, increased attention to the picture book and SBR stimuli and reduced attention to background objects was exhibited. These results suggested that lower cognitive skills and language levels may be associated with reduced attention to salient stimuli and greater engagement with distractor stimuli. The significant difference in receptive language skills between ASD and neurotypical groups may suggest that language differences could be a contributing factor for the differences in gaze behaviour between groups. However, in consideration of the high prevalence of language difficulties in children with ASD (American Psychiatric Association, 2013; Lord et al., 2020), suggests that rather than removing the potential influence of language skills on analyses of group differences in social attention, further exploration of the association between these characteristics, is warranted. Indeed, previous research investigating social attention patterns have similarly reported that autistic children with poorer communication and non-verbal cognitive skills may be less likely to engage with social stimuli, particularly when these tasks have greater verbal demands (Chawarska et al., 2012; Cilia et al., 2019; Thompson et al., 2019). Thus, by gaining a better understanding of these clinical associations in important developmental context such as SBR, this may lead to the development of novel language based or SBR interventions for the improvement of social attention and language skills more broadly. With respect to autism symptom severity, greater attention to SBR stimuli and the scene overall was associated with lower levels of autism severity, as measured by the ADOS-2. While no comparable studies were identifiable, previous research has found that autistic children with better social skills are more engaged in tasks including social stimuli (Bang & Nadig, 2020; Frazier et al., 2016; Major et al., 2021; Norbury et al., 2009). Conversely, greater attention to background objects was associated with greater severity of autism symptoms overall, and specific to RRBs. Thus, the results complement previous research demonstrating significant associations between autism severity and increased attention to non-social or distractor-type objects in the scene (Bacon et al., 2020; Klin et al., 2002; Kwon et al., 2019; Moore et al., 2018). Understanding how social attention patterns relate to symptom severity and social functioning through multi-modal techniques, reflective of real life contexts is critical for establishing its clinical utility as a biomarker in developmental milestones, diagnostic assessments, and treatment outcomes (Risko et al., 2016; van Rijn et al., 2019).

3.6.1. Limitations

The current study has several limitations, and the results should be interpreted in light of these. First, due to the nature of the task and the fluidity of facial expressions, it was not possible to investigate the influence of different emotional expressions on attention to the face or SBR. Although the literature examining the influence of emotional expression on social attention is mixed (Bochet et al., 2021; de Wit et al., 2008; Neath et al., 2013), exploring these relationships in the contexts of a SBR scenario, and potential associations with language outcomes may prove beneficial. Relatedly, recent research has suggested that language skills play an important role in socio-emotional competence (Kalland & Linnavalli, 2022; Scheerer et al.), which in children with ASD can be improved using SBR (Lo & Shum, 2021). Second, attention to the mouth AOI could not be investigated in this study due to the limited spatial resolution with the Eyes AOI. Third, the findings of an association with language were interesting, however further research is now required measuring other facets of language and literacy skills such as expressive language, phonological awareness and story comprehension. Fourth, the sample size of this study was moderate and does not represent the full spectrum of those diagnosed with ASD. Additionally, Children with intellectual disabilities were not represented in this study, nor was the study's gender composition representative, with few female participants. Following from this, while many tests were conducted on this sample, its size made for insufficient statistical power to enable deeper analysis, and the application of stricter methods such as adjusting with Bonferroni corrections.

3.6.2. Conclusion

The results of the study support the use of this SBR eye-tracking paradigm to examine social and joint attention gaze behaviours in autistic children and their neurotypical peers. In this regard, previous eye-tracking studies report mixed results in the social attention patterns of autistic individuals and have emphasized the need to develop and validate more ecologically valid paradigms for investigating these behaviours in autism (Frazier et al., 2017; Mastergeorge et al., 2020; Tsang et al., 2019). In this study, a task using social and distractor stimuli was implemented in an ecologically established SBR activity and demonstrated salient effects across multiple parameters of social attention relevant to autism. The task also confers specific advantages for investigating the temporal sequence of joint behaviours and understanding this social behaviour as its conceptually understood. Moreover, the findings indicate that these relationships may provide useful markers for autism symptoms and cognitive functioning. Drawing from the broader SBR literature, the task offers opportunities to study attentional mechanisms involved in SBR to inform language-based and joint attention interventions and, potentially, other longer term developmental outcomes. Moreover, this task also appears to have some added and specific advantages for the study of joint attention in comparison to previous work.

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4. Cross-Contextual Associations in Social Attention Across Eye-Tracking and Interactive Contexts

Preface

One prominent theme raised throughout this thesis is the variability of findings across the numerous studies, commonly utilising static or dynamic eye tracking contexts, in investigating social attention in autistic children. As has been discussed in preceding chapters, these inconsistencies have impeded the clinical utility of these observations despite the technological advancements and sheer volume of literature dedicated to developing our understanding in this area. As such, researchers have argued for the need to investigate social attention across contexts representative of real-life scenarios, particularly in reference to contexts involving real social interactions. However, research investigating the differences or similarities in social attention patterns across different contexts including social interactions is scare, particularly in younger autistic children.

This chapter builds on the outcomes of previous chapters by incorporating the static and dynamic tasks described. In the same young cohort of autistic children, the associations in social attention patterns observed in a play-based social interaction task, compared to the same patterns in the eye tracking tasks previously described are explored. This within group exploration of social attention patterns brings a unique experimental approach by incorporating the fields most recent conceptual understanding of the natural variability of gaze and the importance of understanding social behaviour in interactive and ecologically relevant contexts.

Abstract

The heterogeneity in research findings across different studies investigating social attention in autistic populations is well noted in the literature. One potential source of this variability is the influence of social context, particularly when comparing screen-based eye-tracking tasks with contexts involving actual social interactions. Yet, there is limited research investigating how social attention across these different contexts relate to each other in autistic children. In the current study, associations in social attention patterns across three different contexts were explored in a young autistic cohort (*N* = 56, 3-12 years). These contexts included: 1) the static eye-tracking task described in chapter 2, 2) the dynamic eye-tracking task described in chapter 3, and 3) a live, play-based social interaction task between the autistic child and a researcher. Correlational analyses indicated moderate positive associations between social interaction and dynamic contexts, and between dynamic and static contexts, with no significant associations between interactive and static contexts. These results contributed to research proposing an underlying influence of social interactions and highlighted the value of investigating social attention across contexts of varying ecological relevance.

4.1. Introduction

There is a sound body of research supporting the view that autistic children display atypical social attention patterns compared to their neurotypical peers (Chita-Tegmark, 2016b; Frazier et al., 2017). Multi-modal research methods, including eye-tracking and behavioural coding of recorded observations have suggested that in autistic children, attention to social stimuli such as the faces and eyes of other people tends to be reduced (Hahn et al., 2019; Jones et al., 2017; Papagiannopoulou et al., 2014; Pellicano et al., 2013; Shic et al., 2022). As an early phase indicator of social cognition and social interaction, there is some evidence suggesting that reduced social attention contribute to poorer social, cognitive and adaptive functioning outcomes throughout childhood and adulthood (Riddiford et al., 2022; van Rijn et al., 2019; Zaidman-Zait et al., 2020). However, the resultant clinical potential of this behavioural phenotype as a diagnostic and treatment biomarker in autistic cohorts (Bradshaw et al., 2019; Murias et al., 2018; Wen et al., 2022) has been hampered by the degree of variability and inconsistencies in findings across studies employing paradigms of varying ecological relevance (Chevallier et al., 2015; Grossman et al., 2019; Mastergeorge et al., 2020).The variability reported may be reflective of the heterogeneity of the condition itself (Eapen et al., 2013; Gui et al., 2020; Li et al., 2020; Rice et al., 2012; Tiede & Walton, 2020), natural variations in gaze behaviours across different contexts (Foulsham & Kingstone, 2017; Gregory & Antolin, 2019; Laidlaw et al., 2011), in addition to the types of tasks and task demands administered (Chawarska et al., 2012; Chevallier et al., 2015; Hochhauser & Grynszpan, 2017). Consequently, gaining a clearer understanding of how social attention patterns vary across different social contexts is critical to improving research translation capabilities and relating these behaviours to broader measures of social and adaptive functioning.

In the last two decades, eye-tracking methodologies have been popularised in research investigating social attention owing to their increasing efficiency and sensitivity in providing an objective, accurate and cost-effective method of investigating these behaviours in a broad range of cohorts with varying levels of intellectual and verbal functioning (He et al., 2019; Plesa Skwerer et al., 2019; Shic et al., 2022). With the development and increasing use of eye-tracking in social attention research, the number of experimental paradigms has also increased, resulting in inconsistencies and mixed findings across studies (Chita-Tegmark, 2016a; Mastergeorge et al., 2020; Moriuchi et al., 2017). Mixed findings have been reported both within and across different types of tasks in autistic samples. For example, some research has reported typical attention to the eyes but reduced attention to the face in autistic preschoolers (Kwon et al., 2019), while other research in children and adults has shown that social complexity and communication demands are moderating factors (Parish-Morris et al., 2019; Robain et al., 2021; Tsang et al., 2019).

The few studies exploring social attention across experimental paradigms have similarly produced variable results. Chevallier and colleagues (2015) compared social attention in autistic and neurotypical children across static, dynamic and interactive eye-tracking tasks, reporting a significant group difference only in the interactive condition, which essentially involved the passive viewing of two children interacting in a video clip. In a different study, the authors reported reduced social attention in autistic adolescents in the screen-based task and similar gaze patterns between autistic and neurotypical adolescents in the live interaction task (Grossman et al., 2019). Contrastingly, a differentiation in social attention was reported between high and low autistic trait college students in a condition where they were led to believe was a live interaction, compared to the same video shown pre-recorded, suggesting an influence of perceived social interaction on gaze behaviour (von dem Hagen & Bright, 2017). Taken together, the results underscore the impact of social context and the incongruity in generalising social attention across screen-based and live interaction contexts.

Previous research has indicated a naturality variability in social attention across different contexts, including those which elicit an influence of anticipatory social interactions on social attention (Foulsham & Kingstone, 2017; Gregory & Antolin, 2019; Holleman et al., 2020). In neurotypical cohorts, gaze behaviour has been shown to vary in response to different task demands and stimuli characteristics (Libertus et al., 2017; Risko et al., 2012), in addition to contexts involving actual or potential social interactions (Foulsham et al., 2011; Freeth et al., 2013; Wu et al., 2013). When comparing social attention between live and passive viewing conditions, neurotypical individuals display reduced attention to faces in live compared to passive contexts, potentially due to the influence of social norms (Gregory & Antolin, 2019; Holleman et al., 2020). There is limited research comparing screen-based and live interaction contexts in autistic cohorts (Grossman et al., 2019; von dem Hagen & Bright, 2017). Given overall inconsistencies reported in this population, this suggests that additional research incorporating within-subject investigations of social attention across screen-based and live interaction contexts is important. Considering the emphasis of early intervention approaches in autism (Fontil et al., 2019; Franz et al., 2022; Petinou & Minaidou, 2017; Tonge et al., 2014), developing a more coherent understanding of cross-contextual associations in gaze behaviours is particularly relevant when attempting to predict how improvements or responses to treatment interventions, observed in more controlled environments, may translate to changes in real-world social behaviour (Cole et al., 2016).

The variability in social attention across different contexts has emphasised the importance of incorporating ecologically relevant paradigms when investigating these behaviours in autistic populations (Chevallier et al., 2015; Chita-Tegmark, 2016b; von dem Hagen & Bright, 2017). Static tasks employing social/object (e.g.,(Almourad et al., 2018;

Ambarchi et al., 2022) and gaze cueing paradigms (e.g., (Böckler et al., 2014; Dalmaso et al., 2016) provide simplistic attentional cues lacking contextual considerations such as background and competing stimuli which are inherently present in natural visual environments. To address these limitations, dynamic and interactive paradigms have been developed to examine gaze behaviour under more natural conditions while still maintaining a degree of experimental control, although achieving the right balance is challenging (Großekathöfer et al., 2021; Holleman et al., 2020). Therefore, it becomes important to examine the associations in social attention across these different contexts, particularly when reflecting on the natural variability of gaze behaviour and behavioural heterogeneity in autistic populations (Foulsham & Kingstone, 2017; Li et al., 2020). Moreover, examining how social attention patterns relate across simplistic and more ecologically relevant paradigms may contribute to our understanding of how real-world social engagement behaviours precipitate some of the developmental challenges in cognitive, language, social skills that are suggested to lead to poorer outcomes across the lifespan in this population (Gulsrud et al., 2014; van Rijn et al., 2019; Zaidman-Zait et al., 2020).

4.2. The Current Study

The main aim of this study was to investigate associations in social attention between a live social interaction task and two screen-based eye-tracking tasks in autistic children. More specifically, the study sought to investigate associations in the frequency and duration of social attention between a live, play-based, social interaction task involving autistic children and an adult researcher, and 1) a dynamic, ecologically relevant eye-tracking task, and 2) a static, more traditional eye-tracking task. Associations in the duration and frequency of social attention between the dynamic and static eye-tracking tasks were also investigated. A secondary aim of the study was to explore the strengths of associations in social attention patterns across the three different contexts.

Although there is limited research comparing social attention patterns of autistic children across live and eye-tracking contexts, it was hypothesised that a positive association in the frequency and duration of social attention between the live social interaction and dynamic eye-tracking contexts would be evident, and the strength of this association would be greater than the association between the social interaction and static contexts. Although findings of reduced social attention across static and dynamic tasks have generally been reporting in eye tracking studies comparing autistic to neurotypical cohorts, there is insufficient research to support a particular hypothesis the direction or strength of this relationship.

4.3. Methods

4.3.1. Participants

The participant sample was drawn from the shared book reading (SBR) study described in the previous chapter. Fifty-six autistic children aged 3-12 years were included in the sample (M = 6.93, SD = 2.76; Male = 47). Children who had previously received a clinical diagnosis of ASD were recruited through the Clinic for Autism and Neurodevelopmental Research (CAN Research) at the Brain and Mind Centre (BMC) of The University of Sydney. Eligibility to participate in the study was confirmed through cut-off scoring for ASD on the Autism Diagnostic Observation Schedule – Second Edition (ADOS-2; Lord et a., 2012), which was administered by research reliable assessors. A medical and physical assessment, including clinical history as reported by a caregiver, was administered to exclude children with symptoms or evidence of severe renal, hepatic, cardiovascular or respiratory illness.

As described in the previous chapter, receptive language (RL) and non-verbal IQ (NVIQ) scores were derived from composite variables. Scores from the the Leiter International Performance Scale - Third Edition (Leiter-3; Roid et al., 2013) or the non-verbal subscales of the Mullen Scales of Early Learning (MSEL; Mullen, 1995) were combined to create a composite NVIQ variable. Scores from the Peabody Picture Vocabulary Test – Fourth Edition (PPVT; Dunn and Dunn, 2007) were combined with the verbal subscale scores of the MSEL to create a composite RL variable. Written informed consent was obtained from a caregiver prior to any study procedures being performed. Human research ethics committee (HREC) approval was obtained from The University of Sydney HREC (Reference numbers: 2013/502; HREC/18/RPAH/157). Participant characteristics are details in Table 4.1.

Table 4.1

Participant Characteristics

Characteristic	**ASD**		
	N	***M (SD)***	**Range**
Age, years	56	6.93(2.76)	3.14-12.81
Male/Female	47/9	-	-
NVIQ composite[a]	49	93.56(18.04)	51-129
RL composite[b]	38	69.08(36.60)	20-135
ADOS CSS			
Total	55	7.53(1.63)	5-10
SA	55	7.38(1.88)	3-10
RRB	55	7.58(1.88)	1-10
SRS-2 Mean T-Scores			
Total	56	76.66(10.10)	56-90
SCI	56	75.89(10.13)	53-90
RRB	56	75.79(11.07)	44-90

Notes. ADOS-2, autism diagnostic observation scale – second edition; ASD, autism spectrum disorder; CSS, calibrated severity scores; MSEL, mullen scales of early learning; NVDQ, non-verbal developmental quotient; NVIQ, non-verbal IQ; PPVT-4, peabody picture vocabulary test – fourth edition; RL, receptive language; RRB, restricted and repetitive behaviours; SA, social affect; SCI, social communication index; SRS – 2; social responsiveness scale – second edition.

[a] Non-verbal IQ composite inclusive of Leiter-R NVIQ and MSEL NVDQ scores

[b] RL composite inclusive of PPVT-4 T-scores and MSEL RL T-scores

4.3.2. Measures

4.3.2.1. Social Interaction (SI) assessment

The Social Interaction (SI) assessment was purpose-built by the research team to evaluate social interaction behaviours between autistic children and trained researchers. The assessment was administered by a trained researcher and comprised of a subset of specific tasks included in Modules 1-3 of the ADOS-2. Tasks were chosen based on their likelihood of facilitating social interactions between participants and researchers. These tasks included response to name, response to joint attention, joint interactive and make-believe play, birthday party, functional and symbolic imitation, and free play. Although not part of the current study, the assessment also included examination of Heart Rate Variability (HRV) as an index of social synchrony, requiring the placement of ECG electrodes and related hardware on both the participant and researcher for the duration of the assessment.

For the purposes of the current study, only the SI free-play task was behaviourally coded to measure social gaze behaviour between the participant and researcher. During the free-play task, various toys from the ADOS-2 kit were used by the researcher to elicit engagement from the participant based on their age and interests. The task was always administered in the same laboratory room at the BMC. The room was fitted with four cameras that were strategically installed in locations most likely capture participants' behaviour regardless of their movement or position within the room. The room was neutral in colour and not decorated. It included a child sized desk and two child sized chairs, one for the child participant and one for the researcher, to encourage levelled eye contact. Administration time of the whole task was approximately 60 minutes, of which the free-play task was approximately 5 minutes in duration.

4.3.3. Eye-Tracking Tasks

There were two eye-tracking tasks administered as measures of social attention. The visual preference (VP) task is a static task developed by Sasson and Touchstone (2014) and has been described in chapter 2 of this thesis. Briefly, the task comprised of 20 media slides, 10 slides included a face adjacent to an object of high autism (i.e., circumscribed) interest, and the other 10 slides were of a face and object low-autism interest. The SBR task was a dynamic task developed by the researcher to examine social gaze behaviours using a novel, more ecologically valid and developmentally relevant paradigm, and has been described in detail in chapter 3. As a summary, the task comprised of a video of an adult reader reading an appropriately aged picture book to the viewer with a background of distractor objects while engaging in controlled bids for joint attention and dyadic interaction. In the current study, only the frequency and duration of participants' gaze to the face and eyes of the adult reader over the whole video are investigated in relation to these behaviours in the other tasks.

4.3.4. Clinical Measures

The ADOS-2 is a play-based behavioral measure of commonly reported autism symptoms falling under the broad domains of Social Affect (SA) and Repetitive and Restrictive Behaviour (RRB; Lord C., 2012). The SA domain encapsulates a diverse range of behaviours including eye contact, facial expressions, verbal and non-verbal communication skills, social reciprocity, and quality of rapport between the child and the assessor. The RRB domain captures stereotypic use of language, excessive or highly specified interests, unusual sensory interests, or hand mannerisms, as examples. The scores on each domain are then combined to achieve a total score as an indication of whether the individual meets the cut-off score for ASD. Calibrated severity scores (CSS) for the Total, SA, and RRB domains were generated, with higher scores indicating greater symptom severity (Gotham et al., 2009).

The Social Responsiveness Scale - Second Edition (SRS-2; (Constantino & Gruber, 2012) was completed by caregivers as a measure of social functioning, producing T-scores in the domains of Restricted Interests and Repetitive Behaviour (RRB) and Social Communication and Interaction (SCI), and in Total. Both measures are commonly used in the assessment of social communication skills in autistic populations (Anagnostou et al., 2015).The means, *SD* and range of scores on the ADOS-2 and SRS-2 are noted in Table 4.1.

4.3.5. Procedure

Once caregiver written consent was provided and eligibility was confirmed, participants would either be administered the SI assessment or eye-tracking tasks first based on room availability and research procedures. The eye tracking tasks were administered in a counter-balanced manner.

4.3.5.1. Administration of the Social Interaction Assessment

Participants and their caregiver(s) entered the room and were given time to acclimatize to their surroundings prior to assessment administration. Once the participant was comfortable, both the participant and assessor would sit at right angles to each other around the desk for the duration of the assessment. Caregivers who preferred to be present in the room would sit in a chair at a distance from the participant and researcher and were requested to not intervene unless specifically requested by the researcher.

4.3.5.2. Behavioural Coding of Free-Play Video Clips

Video clips of the SI free-play task were cut for behavioural coding of social gaze behaviours and ranged in duration from 151.6 to 600 seconds (M = 329.82, SD = 18.25). For the purposes of coding, social gaze behaviour was defined as an occurrence of eye-to-eye contact between the participant and the assessor during the 5-min free play task. Start time tags for each occurrence of the initiation of eye-to-eye gaze were labelled across each of the four video clips produced from the four different cameras simultaneously capturing the interactions between the participant and assessor from four different angles in the testing room. This provided the opportunity to review ambiguous instances of eye-to-eye contact and code for this behaviour with greater certainty. A code of 1 was applied if at least one camera indicated mutual gaze to faces between the participant and researcher. The sample frequency was 25 Hz. Coding was competed using the MATLAB Ground Truth Labeler application. Due to the wide range in duration of the SI free-play task, the frequency and duration of social gaze were compared between the ranges of 151.6 – 300 and 300-600 seconds in those participants whose video clips were greater than 300 seconds in duration. Analyses revealed no significant differences in either variable (Frequency: $F(1,27) = .786$, $p = .384$; Duration: $F(1,27) = .352$, $p = .558$), suggesting that the duration of the task was not a significant influence on the social attention patterns observed in the sample.

Two researchers, who were blind to each other's coding, were involved in coding all video clips and at least 50% of video clips were coded by both researchers. Any discrepancies in coding between researchers were discussed by the research team and a third independent, senior researcher would review ambiguous frames and provide their coding. A kappa range of .80 to .87 indicated moderate to high inter-rater reliability.

4.3.6. Data Analysis

To investigate cross-contextual associations in social attention, correlations in the frequency and duration of gaze to the face were independently examined between the SI free-play, and dynamic and static eye-tracking tasks. For the SI free-play task, the frequency and duration of mutual gaze to faces served as dependent variable (DV). For the dynamic task, the frequency and duration of fixations to the face areas of interest (AOI) across the overall video were included as separate DVs. For the static task, the frequency and duration of fixations to the face AOI overall, were also included as DVs. The means and SDs of social gaze DVs are noted in Table 4.2.

Table 4.2

Frequency and Duration (in seconds) of Social Attention Across Contexts

Social Context	**Frequency**	**Duration (sec)**
	M (SD)	***M (SD)***
Social Interaction	3.98(5.69)	4.25(8.10)
Dynamic	48.73(31.71)	20.63(15.52)
Static	75.75(40.31)	24.94(12.93)

Given the nature of the data, and the dependent correlation comparisons, all analyses were carried out using Spearman's rho correlations. As an additional level of analysis, the relative magnitude of the strength of relationships between the social attention DVs across the three different tasks were explored. As the correlations were derived from a single sample, the procedure of Cohen and Cohen (1983) for comparing of dependent correlations was followed. This approach that has previously been used within broader fields of research (Kim et al., 2021). Spearman's correlations were also used when exploring the relationship between social attention and clinical characteristics including the SA, RRB and Total CSS of the ADOS-2, and the SCI, RRB and Total scores of the SRS-2.

The data of five participants was missing from the SI free-play task as the video clip was not behaviourally coded. Eye-tracking data was missing from another two participants due to low gaze data quality (i.e., below the 20% threshold adopted throughout this thesis and by other studies, e.g., Harrop, 2018; Chawarska, 2012).

4.4. Results

4.4.1. Correlations in Social Attention Across Context

Correlational analyses identified significant positive associations in social attention patterns between the SI and dynamic contexts, and between the dynamic and static contexts, respectively. Moderate positive correlations were found in the *frequency* of social attention between the SI and dynamic tasks ($\rho = .315$, $p = .026$), and between the dynamic and static tasks ($\rho = .348$, $p = .010$). Although not significant, the moderate correlation in the *duration* of social attention between SI and dynamic tasks ($\rho = .253$, $p = .076$) suggested a larger sample size with greater statistical power may have demonstrated a more robust association between these variables. Conversely, no such trend was observed in the *duration* of social attention between dynamic and static tasks ($\rho = .153$, $p = .269$). There were no significant correlations in DVs between the SI and static contexts (Frequency: $\rho = -.006$, $p = .970$; Duration: $\rho = -.193$, $p = .184$).

The next set of correlations explored the relative magnitude of the associations in social attention across the three contexts. The results revealed that the correlation of the *duration* of social attention between the SI and dynamic tasks was significantly larger than the correlation of this variable between SI and static tasks ($T = 2.626$, $p = .006$). Similarly, the correlation of the *frequency* of social attention between SI and dynamic tasks was significantly greater than its correlation between SI and static tasks ($T = 2.098$, $p = .020$). These results suggested that social attention patterns between SI and dynamic contexts were more closely associated than the equivalent patterns between SI and static contexts.

When exploring the relative magnitude of social attention correlations between the dynamic and other tasks, a different pattern of results emerged. The correlations of the *duration* of social attention between dynamic and static, and between dynamic and SI were not statistically different ($T = -.432$, $p = .666$). Similarly, the relative magnitude of the *frequency* of social attention between dynamic and static, and dynamic and SI tasks were also not statistically different (*T*=.169, p = .433). These results suggested that the associations of social attention patterns in the dynamic context relative to the other contexts are relatively similar in magnitude.

4.4.2. Associations Between Social Attention and Clinical Characteristics

4.4.2.1. Autism severity

Exploration of the associations between social attention and ADOS-2 CSS indicated significant negative correlations across all three contexts. There were moderate negative relationships between the frequency of social attention in the SI task and SA CSS (p = .048) and between the duration of social attention in the dynamic task and Total CSS (p = .036). The correlation between the duration of social attention in the dynamic task and SA CSS was modest in size but not significant, indicating a trend to significance with a larger sample size (ρ = -.246, p = .072). There was a strong inverse relationship between the frequency of social attention in the static task and RRB CSS. There were no other significant correlations. Overall, these associations indicated that greater social attention was associated with a lower severity of symptoms across all domains.

4.4.2.2. Social functioning

The correlations between social attention and social functioning revealed moderate-sized correlations between SRS-2 RRB T-scores and both the duration (p < .020) and frequency (p < .042) of social attention in the SI context. The negative correlation coefficients for both the duration and frequency of social attention in the dynamic task with SRS-2 RRB T-scores were modest in size and trended towards significance (p < .80). Given the low statistic power with this sample size, the results suggested a potentially meaningful relationship. The correlations between social attention, ADOS-2 CSS and SRS-2 T-scores are detailed in Table 4.3.

Table 4.3

Spearman's Correlations Between Social Gaze and Clinical Characteristics Across Contexts

Social gaze	ADOS-2 CSS			SRS-2 T-scores		
	SA	RRB	Total	SCI	RRB	Total
SI context						
Duration	-.235	.151	-.089	-.147	-.326*	-.210
Frequency	-.278*	.064	-.178	-.159	-.286*	-.210
Dynamic context						
Duration	-.246 Ɨ	-.217	-.286*	-.126	-.239Ɨ	-.146
Frequency	-.168	-.193	-.217	-.141	-.240 Ɨ	-.158
Static context						
Duration	.016	-.144	-.065	.207	.147	.229
Frequency	-.096	-.452**	-.206	-.002	.046	.026

Note. ADOS-2, autism diagnostic observation schedule – 2nd edition; CSS, calibrated severity scores; RRB, restricted and repetitive behaviours; SA, social affect, SCI, social communication and interaction; SI, social interaction; SRS-2, social responsiveness scale – 2nd edition.

* $p < .05$, ** $p < .001$, Ɨ $p < .80$

4.5. Discussion

The current study explored associations in social attention across three different contexts of varying ecological relevance. As hypothesised, results revealed significant positive associations in social attention patterns between the live social interaction and dynamic eye tracking contexts. There were no significant associations in social attention between the social interaction and static tasks, confirming stronger associations between live and dynamic in comparison with live and static contexts. Additionally, the strength of the association between live and dynamic contexts was comparable with the association between dynamic and static contexts, potentially suggesting that ecologically relevant dynamic paradigms may be a useful predictor of social attention across both real-world and more tightly controlled laboratory settings. Furthermore, the study garnered some evidence that greater severity of restrictive and repetitive behaviours was related to poorer social attention across live and eye-tracking contexts.

When examining the associations in social attention between live social interaction and dynamic eye-tracking contexts, positive associations were evident. The frequency of gaze to the face in the SBR task was positively related to attention to the face during live social interactions, and a similar trend was observed for the duration of social attention across tasks. These associations in social attention were not evident between the social interaction and static eye tracking contexts. While direct comparisons to previous studies are not available, the results do support the notion that experimental conditions involving actual or the potential for social interactions elicit different gaze behaviours to more traditional, static tasks in which only passive viewing is required (Gregory & Antolin, 2019; Holleman et al., 2020; Risko et al., 2012). Moreover, this perspective may support findings across a range of studies in autistic children reporting variability in social attention patterns between tasks including social reciprocity and those in which participants are simply required to look at a screen without any perceived potential for social engagement (Chawarska et al., 2012; Grossman et al., 2019; van Rijn et al., 2019). Interestingly, findings of discrete gaze behaviours in social interaction contexts have also been reported in primate studies (Da Montel, 2016) and in human imaging studies revealing different activation patterns in brain regions involving interactive contexts (Haxby et al., 2020; Ramot et al., 2020; von dem Hagen et al., 2014).

Previous research in neurotypical cohorts has shown that the temporal sequence of events and images has an influence on the distribution of attention in social contexts, and this may be related to expectancy beliefs around social norms (Foulsham & Kingstone, 2017; Laidlaw et al., 2011; Wu et al., 2013). In relation to patterns of social attention in autistic children, it may be that differences in their expectations around social engagement behaviours, potentially due to reduced social learning experiences from the earliest stages in life, exert variable attention patterns in these contexts. Relatedly, reduced social learning experiences may also underlie atypical presentations of other social cognition domains such theory of mind (Poulin-Dubois et al., 2018; von dem Hagen et al., 2014), thus providing a rationale for the variability is social attention exhibited in interactive contexts without any explicit cues for direct engagement from the viewer (Chevallier et al., 2015).

The results of this study also support the idea that the ecological relevance of tasks distinguishes the social attention patterns in autistic children. Social attention between the social interaction and dynamic contexts were more closely related than these same patterns between social interaction and static contexts. Indeed, the variability in social attention reported across different studies (Frazier et al., 2017; Mastergeorge et al., 2020) may in part be due to differences in the approximation of task context and demands to natural interaction contexts, which are considered to be the pinnacle of ecological relevance when measuring social attention (Cole et al., 2016; Risko et al., 2012). The dynamic SBR task employed in this study emulates an important, developmentally appropriate, and ecologically relevant social engagement activity that is frequently practiced in home and educational settings (Hadley et al., 2022; Hayes et al., 2018). By embedding viewer directed bids for joint attention and dyadic interaction, the task facilitates direct engagement at the very least, or potentially, a perceived potential for social interaction; in turn, these features may support its use as a proxy for understanding social gaze behaviours during live social interaction contexts. Conversely, the lack of association between the social interaction and static contexts underscores issues with generalising social gaze behaviours observed in static contexts to natural conditions, and the importance of considering the ecological relevance of tasks when examining and interpreting social attention in autistic individuals (Falck-Ytter, 2015; Grossman et al., 2019; von dem Hagen & Bright, 2017).

In the current study, associations in patterns of social attention between the two eye-tacking contexts were also evident, potentially reflective of a natural bias in attention to salient stimuli, (Aguillon-Hernandez et al., 2020; Smith & Mital, 2013). This natural bias has previously been suggested to be related to the activation of bottom-up attentional processing mechanisms (Großekathöfer et al., 2020; Thompson et al., 2019), often captured in the first few moments of visual allocation to salient stimuli, prior to the activation of higher-order top-down cognitive processing mechanisms (Amso et al., 2014; Xu et al., 2019).

4.5.1. Associations with Clinical Measures

Associations between social attention and clinical measures predominantly suggested that reduced social attention was related to higher repetitive and restrictive behaviours (RRBs). This relationship was mainly demonstrated in the social interaction task, whereby the reduced frequency and duration of social attention was inversely related to RRBs as reported by caregivers, with a similar trend observed in the dynamic task. A strong inverse relationship was also evidenced between the severity of RRBs measured in the ADOS-2 and the frequency of social attention in the static task. Research is scarce on direct associations between social attention and RRBs in autistic children, however there is some longitudinal evidence relating the influence of atypical RRBs measured in the first years of childhood with inattention and socialisation skills more broadly in later years (Wolff et al., 2014; Zachor &

Ben-Itzchak, 2019), and of improvements in RRBs in response to a social orientation intervention (Alvares et al., 2019). On the other hand, associations between social attention and social communication skills measured through observations or caregiver report were relatively weak, with higher social attention in interactive and dynamic contexts weakly correlated with reduced severity of social communication and overall symptoms, respectively. The weak associations between social attention and social functioning may be reflective of the broadness domains which fall under social communication, including language, non-verbal and verbal communication skills, social reciprocity and social motivation (Gotham et al., 2009; Lord C., 2012). Equivocal findings relating social attention to broader clinical measures of social functioning have also been reported in other studies (Morrison et al., 2020; Riddiford et al., 2022), and highlight the challenge in developing social attention as a biomarker of social functioning in autism (Hamner & Vivanti, 2019; Shic et al., 2022).

4.5.2. Limitations

There are several limitations in the current study. The limited sample size prevented the application of Bonferroni corrections to correlational analyses, and so caution in interpreting associations beyond the current sample is warranted. While the current study's results provide an indication of potential associations in social attention across different contexts, future research with larger sample sizes and corrected correlational analyses may yield greater confidence in the implications of cross-contextual associations if similar findings are replicated. As the durations of each task varied, variability in attention patterns across the duration of each task may have differentially affected the cross-contextual associations reported (Del Bianco et al., 2020; Del Bianco et al., 2018). In further consideration of potential expectancy effects and top-down and bottom-up processing mechanisms, future research would benefit from utilizing time course analyses to explore differences in attention patterns across the three contexts as a function of time (Amso et al., 2014). Moreover, as the study included only a small number of female participants, it is unclear whether the female social attention phenotype (Del Bianco et al., 2022; Frazier et al., 2021b) may have moderated any reported effects. Lastly, as neurotypical participants were not included in the study, the similarities or differences in cross-contextual associations between neurotypical and autistic children could not be investigated.

4.5.3. Conclusion

The current study explored associations in social attention across live social interaction, and dynamic and static eye-tracking contexts. The strength of the association between interactive and dynamic contexts suggested that social interactions or direct social engagement strategies may influence social attention in a different way to these behaviours under passive viewing conditions in static tasks. Given the natural variability of gaze across different social contexts, and the established variability in social attention patterns of autistic children reported in the literature, the results of the study underscored the importance of investigating social attention across these different contexts. The results contributed to previous research promoting the importance of understanding the relationships in social attention across tasks of varying ecological relevance, thereby potentially improving the clinical utility of social attention observed in controlled contexts to real-world settings.

4.6. References

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5. General Discussion

5.1. Thesis Summary

5.1.1. Cross-Contextual Patterns of Social Attention

The overall objective of this thesis was to investigate patterns of social attention across different contexts in a cohort of young children with ASD, and explore their associations with autism symptomatology, and cognitive and social functioning. In line with this, the first specific aim of the thesis was to examine differences in patterns of social attention between children with ASD and an age-matched neurotypical cohort. To address this, an eye tracking task was conducted within a static context. To address the second aim, social attention, including joint attention, were compared between autistic and neurotypical young children in a dynamic eye tracking context using a novel, purpose-built shared book reading (SBR) task. The third aim of the study was to examine the cross-contextual associations in social attention across the static and dynamic eye tracking contexts, and a live, play-based social interaction context, in the young autistic cohort. Across all three contexts, the associations between social attention and relevant clinical characteristics were explored. The collective results produced by this series of studies provide evidence to support the central hypotheses of this research project, namely that context, task, and interaction effects are relevant for explaining the nature of reduced social attention related factors in ASD cases.

Overall, the results of the two eye tracking studies involving both static and dynamic contexts indicated that both tasks were successful in discriminating between the social attention patterns of children with ASD and their neurotypical peers. As described in chapter 2, the use of an established, visual preference static task revealed a general pattern of reduced attention to social as well as non-social stimuli for children with ASD, regardless of the presence of objects of circumscribed interest (CI). In chapter 3, the development of an ecologically and developmentally relevant SBR paradigm for investigating social and joint attention behaviours in a dynamic, eye tracking context was described. In this context, the results showed that compared to their neurotypical peers, children with ASD consistently exhibited reduced attention to salient social stimuli and the SBR activity in general.

Taken together, the reduced social attention patterns reported across both static and dynamic contexts support the first hypothesis of this thesis, that compared to neurotypical peers, ASD adolescents display patterns of reduced social attention across static and dynamic contexts. These results are consistent with meta-analytic results concerning social attention in children and adults with ASD, including those focusing specifically on eye-tracking tasks, indicating that despite the heterogeneity in tasks and outcome measures, there is an overall pattern of reduced social attention in children with ASD (Constantino et al., 2017; Del Bianco et al., 2020; Rice et al., 2012; Stevens et al., 2019). The results also lend support to the social motivation hypothesis, which posits a general reduction in attention to social stimuli in this clinical population (Chawarska et al., 2012).

Beyond this, the results from the study in chapter 2 also demonstrate that children with ASD displayed reduced joint attention behaviours, which support the second hypothesis of this thesis. This finding is consistent with previous dynamic eye tracking studies reporting reduced joint attention in children with ASD (Chawarska et al., 2012; Franchini et al., 2017; Korhonen et al., 2014; Krstovska-Guerrero & Jones, 2016; Swanson & Siller, 2013). However, previous research focused on dynamic eye tracking tasks that reduce joint attention to gaze cueing effects or attention to the target object alone (Cilia et al., 2019; Frischen et al., 2007; Leekam et al., 1997). In the SBR paradigm developed and implemented in chapter 2, joint attention was examined as its conceptually understood, that is, the temporal, goal-directed social behaviour involving the shared awareness between two people (Mundy, 2018). By segmenting the temporal sequence of joint attention, the results indicate that in comparison to typically developing children, children with ASD spend less time attending to the relevant stimuli throughout the joint attention process. Additionally, the positive correlations in attention to relevant stimuli across the sequence of joint attention suggested that when engaged, children with ASD do understand the spatio-temporal relationships inherent in joint attention. This finding stands in contrast to the findings reported by von dem Hagen and colleagues (2017)(von dem Hagen & Bright, 2017). This may potentially indicate that autistic children's inferential understanding of the nature of joint attention is intact, however the salience in engaging in this social behaviour is reduced (Jaworski & Eigsti, 2017). This interpretation would be consistent with the social motivation hypothesis as well as Kanner's original observations of reduced social responsiveness (Chevallier et al., 2012; Kanner, 1943). Broadly speaking however, the findings of reduced joint attention in this naturalistic and developmentally relevant context indicate that these results may be generalisable to real life settings in this age group.

The results of the last study reported in chapter 4, provided evidence that in children with ASD, context plays an important role, with differential patterns of social attention identified across three contexts. Here, social attention was positively related between the live interactive and dynamic contexts, and in the dynamic and static contexts. Meanwhile, no significant correlations between the live interactive and static contexts were found. While sample size and statistical power may have influenced these null findings, as will be discussed below, the results nevertheless are supportive of the thesis' third hypothesis, which proposed that there would be differences in social attention across contexts. Additionally, they support the hypothesis that the greatest difference seen between the interactive and static contexts, which would hold true even if the marginally significant correlations were to be taken into consideration, given their relative magnitude. The commonality in social attention across live interactive and dynamic contexts suggests that there is an underlying factor in these more naturalistic contexts cueing participants to attend to these social stimuli differently to a static context. Emerging research in typically developing and ASD populations have proposed that social contexts involving actual or perceived social interactions may differentiate social attention to static contexts where only passive viewing is required, a proposition which receives support by the findings of this thesis (Cañigueral & Hamilton, 2019; Foulsham & Kingstone, 2017; Frazier et al., 2017).

5.1.2. Associations Between Social and Non-Social Attention and Clinical Characteristics

The studies in this thesis explored the associations between social attention and clinical characteristics including the severity of autism symptoms, cognitive skills, and social functioning. Across all three contexts, there were indications that reduced social attention was associated with greater symptom severity, poorer social functioning, or both. Evidence of these relationships supported this thesis' final hypothesis and were consistent with an accumulating body of research suggesting that reduced social attention is associated with greater symptom severity or poorer social functioning more broadly (Riddiford et al., 2022).

Due to the limited research to date, a hypothesis of the predicted direction relating social attention and cognitive skills in the dynamic context was not made. Nevertheless, broader research findings would suggest that relationships do exist. In this regard, the current studies found some indications that greater engagement with the SBR activity was associated with receptive language skills and non-verbal IQ, respectively, in the autistic cohort. These results build on previous research reporting an association between social attention, receptive language and NVIQ (Chawarska et al., 2012; Plesa Skwerer et al., 2019). They also contribute to the evidence base linking joint attention with language skills (Gulsrud et al., 2014; Mundy, 2009) and SBR practices (Caldas & Flores, 2021; Farrant & Zubrick, 2013; Wicks et al., 2022; Zimmer, 2015). Moreover, these results serve to highlight the importance of examining the relationships between language skills and social attention more broadly, which in the real world are so intimately intertwined, particularly in contexts involving social interactions (Horsley et al., 2014). Indeed, there is accumulating evidence indicating that together with cognitive functioning, social attention and language skills are important prognostic factors in the long-term adaptive functioning outcomes in ASD (American Psychiatric Association, 2022; Arciuli et al., 2013; Baixauli et al., 2021; Lord, Brugha, et al., 2020; Magiati et al., 2014; Pickles et al., 2020; Zaidman-Zait et al., 2020). In this regard, the results of this thesis' studies provide a unique contribution to this body of knowledge.

Another notable finding of this thesis was the associations between social and non-social attention patterns with restricted and repetitive behaviours (RRBs) across all three contexts. Specifically, in both the static and dynamic contexts, greater attention to faces, as well as salient SBR stimuli, were associated with a lower severity of RRB symptoms, as measured by the ADOS-2. In the live interaction context, greater social attention was associated with better functioning in the RRB domain of the informant-based SRS-2, a more general measure of social functioning commonly used in ASD research (Anagnostou et al., 2015). This finding should stand out given that there is limited research directly comparing social attention with autism symptomatology in the RRB domain; most research examining the two have focused on overall ASD severity or social functioning (Riddiford et al., 2022). However, there is some existing research to suggest that social attention may be associated with RRB symptoms. Earlier eye-tracking studies employing the same visual preference task in a in static context reported similar inverse relationships between social attention and RRBs (Sasson et al., 2008; Unruh et al., 2016). In a more recent study examining the effects of a dynamic, game-based intervention to improve social orientation in children with ASD, results indicated that post-intervention, greater improvements in attention to faces corresponded with improved functioning in the RRB domain (Alvares et al., 2019). There is no research the author is aware of specifically investigating the relationship between attention to social cues and RRBs in a live interaction setting. However, recent evidence of inverse associations between RRB and social engagement behaviours more broadly, observed interactively (Lami et al., 2018) and through caregiver reports (Uljarević et al., 2021), suggests more research investigating this relationship is warranted.

Understanding non-social attention patterns in social contexts, and their relationship to clinical characteristics is an important component of social attention research in ASD (Ambarchi et al., 2022; Canu et al., 2021; Frazier et al., 2017; Salley & Colombo, 2016; Watson et al., 2015). Although this was not the specific focus of thesis, it was considered in the incorporation of non-social stimuli in both static and dynamic eye tracking tasks, as described in Chapters 2 and 3, respectively. As befitting a static context, the visual preference task was able to differentiate the influence of objects of CI or non-CI interest on social and non-social attention patterns. In this context, there was a general pattern of reduced attention to both CI and non-CI objects in children with ASD compared to their neurotypical peers, although the influence of CIs did appear to be greater in the autistic cohort. In addition, greater attention to non-CI objects was associated with better social functioning overall, and across SCI and RRBs domains independently, based on caregiver report. In the dynamic context, it was not possible to differentiate in the influence of CI and non-CI objects on attention patterns, although both were included in the background as distractor stimuli. Contrary to the results in the static context, in this dynamic context children with ASD displayed greater attention to these objects in comparison to the neurotypical group, and this was associated with more severe symptoms overall and in relation to RRBs.

At first glance, these findings may appear paradoxical. On the one hand, in the static context, children with ASD displayed reduced non-social attention overall, and this was related to better functioning across SCI and RRB domains with respect to non-CI objects. On the other hand, in the dynamic context, these children displayed increased non-social attention which was related to increased symptom severity overall and in relation to RRBs. However, if one considers the nature of each task, the saliency of non-social stimuli across both tasks differs. In the static context, both social and non-social stimuli are presented together against a black background and are perceptually salient to the task, changing with each slide. Whereas in the dynamic context, the salient cues are within the SBR activity involving the adult reader and the picture book, whilst the background non-social stimuli are irrelevant to the task. Through this perspective, the results may indicate that the relative saliency of cues, across social and non-social domains, may be a predictive factor in the attentional patterns and symptomatology of children with ASD. This understanding is consistent with neuroimaging findings of atypicalities in salience and domain general attention networks and their associations with autism symptoms (Clements et al., 2018; Keehn et al., 2016).

Overall, the findings across the studies in this thesis provided evidence suggesting that children with ASD exhibit atypical social and non-social attention patterns and this mapped onto higher autism symptomatology and poorer social functioning, particularly in relation to RRBs. In support of these behavioural findings, there is substantial neurological evidence reporting atypical connectivity across visual, salience and social networks and their association with characteristic symptoms of ASD including RRBs (Delbruck et al., 2019; Green et al., 2016; Keehn et al., 2016; Keehn et al., 2021; Murphy et al., 2017; Uddin et al., 2013; Wylie et al., 2020). Taken together, these findings suggest that atypical social and non-social attention patterns may be important predictors of poor social responsiveness and heightened RRBs, observations that were initially reported by Leo Kanner (1943), and reflective of the SCI and RRB domains pertinent to the diagnosis under the current DSM-5 (American Psychiatric Association, 2022; Kanner, 1943).

5.1.3. Conceptual and Clinical Implications

5.1.3.1. Conceptual Implications

The results of this research projects have relevant conceptual implications. Firstly, findings of reduced social attention across all three contexts lent additional credence to the social motivation hypothesis, which posits that the intrinsic reward value or motivation to attend to social stimuli is reduced in ASD (Chevallier et al., 2012). However, the theory implicitly projects a uni-directional role, suggesting that impairments in social attention early in life lead to cascading effects in the development of social cognition and social skills, and therefore poorer social functioning more broadly (Chevallier et al., 2012). Researchers have argued that the theory does not consider factors such as the bi-directional role of eye gaze or social attention more generally (Jongerius et al., 2020; Mundy & Bullen, 2022); interpersonal aspects of social cognition (Mundy & Bullen, 2022; Osborne-Crowley, 2020); the interplay of both top-down and bottom-up attention mechanisms (Connor et al., 2004; Keehn et al., 2013; Mundy & Bullen, 2022); or, how social interactions may influence social attention (Foulsham, 2020; Frazier et al., 2017). Additionally, recent reviews of the social motivation hypothesis using neuroimaging as well as behavioural methods have reported that atypical non-social reword processing and individual variability are also observable characteristics in this clinical population, concurrent with socially related atypicalities (Bottini, 2018; Clements et al., 2018; Neuhaus et al., 2019). It is potentially in light of these findings that it has been proposed that rather than relinquishing the theory altogether, it should be refined to account for these bi-directional influences, atypical non-social characteristics as well as individual differences (Connor et al., 2004; Mundy & Bullen, 2022; Mundy, 2019; Neuhaus et al., 2020; Paul et al., 2021).

5.1.3.2. Clinical Implications

An increasingly important direction in this research field, is developing research tools that can accurately predict or assist in earlier diagnosis or response to treatment interventions (Bridgemohan et al., 2019; Frye et al., 2019; Klin, 2018; Loth et al., 2016). There is a breadth of cross-modal research supporting the atypical divergence of social attention from the earliest stages of life and throughout childhood, with accumulating evidence of its effects on developmental and adaptive outcomes (Bast et al., 2019; Frazier et al., 2017; Ji et al., 2018; Keehn et al., 2016; Reisinger et al., 2020). In turn, this has propagated researchers to examine its utility as a diagnostic and treatment biomarker (Klin, 2018). Recent years have seen researchers increasingly employing techniques such as eye-tracking, artificial intelligence (AI) and machine learning approaches for screening, diagnosing, or measuring responses to interventions in ASD populations (Ahmed et al., 2022; Bradshaw et al., 2019; Camero et al., 2021; Drimalla et al., 2020; Kanhirakadavath & Chandran, 2022; Reisinger et al., 2020; Shahamiri & Thabtah, 2020; Shic et al., 2022; Wen et al., 2022). These developments are also a reflection of general societal trends in healthcare applications of digital and AI technologies for clinical purposes (Leo et al., 2020; Senbekov et al., 2020; Wani et al., 2022). Advantages such as objective data collection methods and perceived cost efficiencies have excited researchers for the research translation potential of using methods such as eye tracking in the early screening and diagnosis of ASD in particular, yet these approaches are still in infancy (Klin, 2018).

Not necessarily unique to this topic, progress has been hampered by inadequate sensitivity and specificity (Levy et al., 2020; Pierce et al., 2016; Wen et al., 2022); phenotypic and individual heterogeneity (Moore et al., 2018; Sánchez-García et al., 2019; Shic et al., 2022), and a lack of clarity of how the observed variability across different studies and contexts can inform clinical practice (Anagnostou et al., 2015; Hamner & Vivanti, 2019;

Morrison et al., 2020; Riddiford et al., 2022). Even with further optimisation of eye tracking methodologies and reporting standards, and replication studies using established task paradigms (Ambarchi et al., 2022; Holmqvist et al., 2022; Venker et al., 2019; Webb et al., 2020), moderating factors such as individual and symptom heterogeneity, and the variability of gaze across social contexts are unlikely to change. Potentially, by accounting for the variability in social attention across contexts, as the results of this thesis indicate, it may be possible to improve the sensitivity and specificity of a combined battery of social attention measures, thereby improving overall accuracy rates. In turn, this may encourage researchers to contribute to the efforts by investing more in replication studies and standardization efforts across different autistic cohorts, and thereby pique greater clinical interest (Bridgemohan et al., 2019; Frye et al., 2019).

5.1.4. Limitations and Future Research Directions

Like all studies, those that make up the current research project are not without their limitations, of which there are several. First, whilst sample size was quite standard for this field of research, it was still limited, leading to issues of statistical power, and an inability to carry out sub-group analyses. With respect to statistical power, several findings were marginally significant at the $<.10$ level. Given the direction and the size of the estimates, it is possible to hypothesize that a larger sample size would generate different findings. With respect to sub-group variability, while there are mixed findings (Del Bianco et al., 2022; Harrop et al., 2018a), a sizeable body of research has presented evidence pointing to differences in social attention between female and male children with ASD (Frazier et al., 2017; Harrop et al., 2018b; Harrop, Jones, Zheng, et al., 2019; Harrop, Jones, Sasson, et al., 2019). In a recent review examining sex-based differences in SCI skills, results indicated that in general, females with ASD had better SCI skills compared to their male counterparts (Wood-Downie et al., 2020). However, how sex-based differences in social attention potentially contribute to these differences, and how this may relate to clinical characteristic and developmental outcomes is not clear (Cummings et al., 2020; Kaat et al., 2020; Mahendiran et al., 2019; Mundy & Bullen, 2022). In addition, potential sex-based differences in social attention across different contexts is yet to be addressed. Together, these gaps in the research field indicate that future research in characterising these differences and how they relate to developmental and adaptive functioning outcomes is important.

To address the research aims of this thesis, a broad age range spanning early childhood was selected. Although reduced social attention throughout the lifespan appears to be a persistent characteristic in ASD (Chita-Tegmark, 2016b; Frazier et al., 2017), age-related effects on social and non-social attention have previously been reported in ASD (Del Bianco et al., 2020; Elison et al., 2012; Fujioka et al., 2020; Kaliukhovich et al., 2019). Longitudinal studies are therefore needed to investigate developmental changes in social attention and their relationship with autism symptomatology and functioning outcomes.

Another important limitation of the research project was that it was not designed to parse out potential influences on social attention in relation to characteristics underlying the heterogeneity in ASD. As has been discussed throughout this thesis, there is a well-noted and significant degree of heterogeneity in ASD populations. This heterogeneity is reflected in symptomatology and individual variability, prevalent comorbidities such as ADHD, and the variability in cognitive and language profiles (American Psychiatric Association, 2022; Masi et al., 2017; Mundy, 2019; Nevill et al., 2019). In relation to autism symptomatology, the reported associations between social attention and total, SCI and RRB domains may provide an indication of the bi-directional influences between these factors, although results should be cautiously interpreted as Bonferroni corrections for multiple analyses were not applied due sample size restrictions.

Additionally, the influence of individual variability was not examined. In the static and dynamic tasks, individual variability was accounted for in the proportional calculation of the dependent variables measuring social attention in those contexts. In the cross-contextual study described in chapter 4, individual variability was not accounted for, another limitation of the study. However, research has previously proposed that individual variability may be an important consideration in our understanding of social motivation and social cognition more broadly (Constantino et al., 2017; Mundy, 2019). In social attention research, a recent, dynamic eye tracking study quantified the idiosyncrasy of gaze patterns in children with ASD as a new measure designed to reflect the individual variability in this cohort (Avni et al., 2019). The results suggested greater accuracy than traditional outcomes measures and significant associations with ASD severity and cognitive scores (Avni et al., 2019). The study also highlighted the value of strategically considering the choice of outcome measures based on sample characteristics as well as the interpretation of findings in light of proposed underlying mechanisms of social attention and their relationship with broader functioning measures (Avni et al., 2019).

To date, most studies investigating social attention in children with ASD apply methodological techniques to parcel out any potential effects of intellectual or language impairments on outcomes. For example, children with lower IQ or poor verbal skills have been excluded from study participation (Amestoy et al., 2021; Grynszpan & Nadel, 2015; Jarrold et al., 2013; Tager-Flusberg et al., 2005), or analytic approaches covarying for IQ or language skills are applied (DiCriscio et al., 2016; Gale et al., 2019; Müller et al., 2016; Sasson & Touchstone, 2014). However, parsing out their potential influence also undermines efforts to improve our understanding of how these important co-occurring characteristics may influence to the variability in social attention patterns observed, and their association with broader measures of social functioning. Although limited, previous research has suggested that cognitive skills may have a significant impact on social attention and its relationship with social functioning (Chawarska et al., 2012; Rice et al., 2012). Furthermore, recent evidence suggests that minimally or non-verbal children with ASD direct less attention to social stimuli compared to their autistic peers who have higher verbal skills, potentially resulting in even poorer developmental outcomes (Plesa Skwerer et al., 2019; Tager-Flusberg & Kasari, 2013). In the individual studies comprising this thesis, participants were not excluded based on cognitive or verbal functioning, nor was their potential influence parsed out of analyses. While the results of the dynamic task provided an indication that higher cognitive and language skills were associated with social attention, methodological and sample size restrictions limited analyses of these associations across contexts. Future research would benefit from directly examining the aims of this thesis in autistic children with varying language and cognitive profiles, particularly those with poorer skills in these domains.

In children with ASD, neuropsychiatric comorbidities are common (Antshel & N. Russo, 2019) . Of these, epidemiological research suggests that ADHD is the most prevalent, with recent studies suggesting that up to 76.8 % of children with ASD have comorbid ADHD (Antshel & N. Russo, 2019; Rau et al., 2020; Stevens et al., 2016). Due to the high prevalence rates and overlapping symptom profiles, a growing body of research is being directed to understanding shared mechanisms (Antshel & N. Russo, 2019; Braithwaite et al., 2020; Wang et al., 2019), and the variability of social attention across ASD/ADHD, ASD, and ADHD subtypes (Gui et al., 2020; Ioannou et al., 2020). Importantly, there is evidence to suggest that children with ASD/ADHD experience greater symptom severity and poorer developmental outcomes than those with ASD alone (Ashwood et al., 2015; Wang et al., 2019; Ward et al., 2022; Zachor & Ben-Itzchak, 2019). However, the contribution of social attention to these outcomes are yet to be determined. A limitation of this research project was that data on comorbidities such as ADHD was not collected, preventing consideration of its potential effects on the results reported. In the future, investigating the variable influence of common comorbidities is likely to enhance our conceptual understanding of social attention in ASD, thereby facilitating the development of personalized intervention approaches and more accurate biomarkers for diagnostic and treatment outcome purposes (Hawks & Constantino, 2019; Ioannou et al., 2020).

Despite these limitations, the studies that make up this thesis, both severally and collectively, provide both methodological and substantive contributions in a field of research that is characterized by these common issues. The studies were developed with previously cited limitations in mind, in particular pertaining to instrument and task selection, as well as measurement. Future research should continue to attempt to mitigate or otherwise address the most relevant limitations in their research designs as the field continues to progress.

5.1.5. Concluding Remarks

Overall, the results reported across all three studies contributed to research indicating that children with ASD do display a general pattern of atypical attention patterns to social and well as non-social stimuli, and this may contribute to greater autism severity, and poorer language, cognitive and social functioning outcomes (Frazier et al., 2017; Mundy et al., 1990; Riddiford et al., 2022). This thesis also provided two unique contributions to the research field. Firstly, the development of a novel, dynamic eye tracking task including a shared book reading paradigm was efficacious in discriminating in the social and non-social attention patterns between children with ASD and neurotypical children. There was also some evidence to suggest that these attentional patterns were related to clinical characteristics in the hypothesised directions. In the future, this ecologically and developmentally relevant task could potentially be developed as an early intervention to improve social attention and joint attention skills, or as an early screening measure in home settings for toddlers at high risk for or suspected to have ASD.

Secondly, the investigation of social attention patterns across multiple social contexts of varying ecological relevance suggested underlying commonalities across live and dynamic, and dynamic and static contexts, respectively. Potentially, adopting this cross-contextual approach in future studies may bridge the challenges in generalising findings from controlled laboratory contexts to real life settings (Anagnostou, 2018; Hamner & Vivanti, 2019; Risko et al., 2016). An additional strength of these cross-contextual findings was that social attention was measured in the same cohort of children, potentially minimizing the influences of individual and phenotypic heterogeneity in this population (American Psychiatric Association, 2022; Mundy, 2019). Although as discussed in the section above, investigating the variable influence of these heterogeneities more closely would benefit future research and research translation efforts.

The conceptual implication of the collective findings would suggest there are benefits to adopting an integrated, cross-contextual approach to the measurement of social attention in children with ASD. This could lead to a more unified understanding of social attention and its role in the hypothesised cascading effects on important developmental, longer term social, and adaptive functioning outcomes (Lord, McCauley, et al., 2020; Magiati et al., 2014; Mundy & Bullen, 2022; Zaidman-Zait et al., 2020). In turn, this may facilitate greater research translation efforts in establishing social attention as a clinically useful and universal biomarker in autistic populations (Klin, 2018), and potentially, broaden its utility to other populations experiencing difficulties in guiding their social behaviour to fit society.

6. References

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7. Appendix A: Chapter 2 Published Manuscript

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ORIGINAL PAPER

Evidence of a reduced role for circumscribed interests in the social attention patterns of children with Autism Spectrum Disorder

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Abstract
Reduced social attention is characteristic of Autism Spectrum Disorder (ASD). It has been suggested to result from an early onset and excessive influence of circumscribed interests (CIs) on gaze behaviour, compared to typically developing (TYP) individuals. To date, these findings have been mixed. The current eye-tracking study utilised a visual preference paradigm to investigate the influence of CI versus non-CI objects on attention patterns in children with ASD (aged 3–12 years, n = 37) and their age-matched TYP peers (n = 30). Compared to TYP, social and object attention was reduced in the ASD group irrespective of the presence of CIs. Results suggest a reduced role for CIs and extend recent evidence of atypical attention patterns across social and non-social domains in ASD.

Keywords Autism spectrum disorder · Circumscribed interests · Eye-tracking · Social attention · Object attention · Gaze

Atypicalities in attention to social information is central to diagnostic criteria for autism spectrum disorder (ASD). The early-age onset and potential cascading effects on social communication and functioning skills has led to a proliferation of research investigating gaze behaviour as a biomarker for early diagnosis and as a potential target for intervention (Bradshaw et al., 2019; Frye et al., 2019; Guastella et al., 2008; Shic, 2016; Webb et al., 2020). Research utilising eye tracking technology has revealed reduced social attention across a range of gaze behaviours, such as the duration of fixations to the eyes and face (Frazier et al., 2017; Klin et al., 2002), the processing of faces and emotional expressions (Black et al., 2017; Dawson et al., 2005), the exploration of, and disengagement from, social stimuli (Chawarska et al., 2010; Sasson et al., 2008), orienting to gaze and gaze following (Senju, 2004; Gillespie-Lynch, 2013), joint attention (Franchini et al., 2017), and social cueing (Chevallier et al., 2013). Reduced attention to social cues has been demonstrated in infants as young as six months of age (Chawarska et al., 2013), across childhood and also throughout adulthood (Chita-Tegmark, 2016; Frazier et al., 2017). Moreover, there has been growing speculation that reduced attention may contribute to the observed difficulties in social and adaptive functioning (Klin et al., 2002; Poon et al., 2012; Rice et al., 2012; Tang et al., 2017).

There has, however, been much debate about the extent to which differences in social attention are moderated by context and their specificity to social cues. For example, circumscribed interests (CIs), considered to be a factor in the characteristic restrictive and repetitive behaviour profile in ASD (South et al., 2005; Turner-Brown et al., 2011), have been reported to induce biases in visual attention patterns across childhood in ASD (Elison et al., 2012; Sasson et al., 2011; Sasson & Touchstone, 2014). Sasson and Touchstone (2014) investigated the influence of objects of circumscribed or High Autism Interest (HAI; for example, transportation vehicles, mechanical instruments) and Low Autism Interest (LAI; for example, household items, plants) on social

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attention patterns in thirty young children with and without ASD. They developed a visual preference task involving a series of 20 images of a face paired with either a HAI or LAI object and found that compared to typically developing (TYP) children, children with ASD were slower to orient to and maintain attention to faces when they were paired with HAI objects, however there were no group differences in social attention in the presence of LAI objects. The ASD group in this study also exhibited a greater preference to attend to HAI relative to LAI objects, complementing findings from earlier studies demonstrating an early-onset and discrete preference in children with ASD to explore and perseverate their attention on CIs in comparison to their TYP peers (Elison et al., 2012; Sasson et al., 2011). In a follow-up study with 87 school-age children aged 6 to 10 years, reduced social attention in the presence of HAI was also demonstrated, however this finding was specific only for male participants with ASD; the attention patterns of female participants with and without ASD were not significantly different (Harrop et al., 2018b). In addition to potential phenotypic variations across sexes, the results of these studies suggested that CIs may moderate attention patterns to both social and non-social elements of a scene from an early age in life and therefore potentially represent an important characteristic in children with ASD.

Other studies investigating the unique influence of CIs on social attention patterns in children with ASD however, have led to variable findings. The visual preference task described above was implemented in a study by Unruh et al., (2016) with results indicating that both adolescents with ASD (n = 41) and their TYP (n = 34) peers demonstrated a preference to attend to HAI compared to LAI objects and reduced social attention in the presence of HAI objects. Furthermore, analysis of between-group differences revealed a preference to look at both object types (HAI and LAI) in the ASD group, while the TYP group preferred to look at faces. A similar finding was reported by Harrison & Slane (2020), with reduced attention to faces in children and adolescents with ASD (n = 16) across object types, and interestingly, a variable influence of HAI on social attention in the TYP (n = 20) but not the ASD group (n = 16). These results are consistent with other eye-tracking studies reporting a similar influence of CIs in ASD and TYP participants, concurrent with reduced social attention in participants with ASD specifically, throughout development (DiCriscio et al., 2016; Mo et al., 2019; Traynor et al., 2019). Findings of reduced social attention in ASD independent of the influence of CIs across childhood lend support to the social motivation hypothesis, which posits an intrinsic, early-onset impairment in the motivation to attend to and engage with socially relevant stimuli, leading to reduced social learning experiences and cascading effects in overall socio-cognitive and social skill development (Chevallier et al., 2012).

Research exploring the relationship between social attention patterns and overall social functioning have led to similarly equivocal findings. There have been some longitudinal studies reporting a relationship between reduced social attention in infancy and poorer language and theory of mind skills in early childhood (Brooks & Meltzoff, 2015; Poon et al., 2012), however other studies in older children with ASD have not yielded significant associations between social attention and social functioning measures (Fujioka et al., 2020; Unruh et al., 2016; van Rijn et al., 2019). Interestingly, the landmark study by Klin and colleagues (2002), as well as Rice et al., (2012) found that greater attention to objects rather than reduced attention to social stimuli, was associated with greater social impairment, while Sasson (2008) reported a positive correlation between exploration of object stimuli and social impairment. The variability in correlational findings between social attention and functioning suggests further exploration inclusive of non-social attention patterns is warranted. Consistent with the social motivation hypothesis, the imbalance of attention to objects over social stimuli has similarly been theorised to lead to fewer social learning experiences and therefore facilitative of the day-to-day social challenges experienced by individuals with ASD (Sasson et al., 2008).

There are equivocal findings across previous studies, suggesting on one hand that the excessive influence of CIs determines the variability in social attention patterns in ASD, and on the other hand, that social attention in this population is reduced irrespective of stimuli and context. This presents a need to better understand how CIs influence the attention patterns of children with ASD and their TYP peers. Thus, the goal of this study was to investigate the influence of CIs on social and object attention patterns in children with ASD compared to TYP peers using established task and outcome measures, and to explore the relationship between these patterns and social functioning. An established visual preference task was employed to facilitate comparability with past research. Based on recent findings, it was hypothesised that a reduction in social attention would be evident in the ASD group regardless of the presence of CIs. It was also hypothesised that both ASD and TYP groups would exhibit greater attention to HAI (i.e., CIs) compared to LAI objects. No hypotheses were made regarding the relationship between attention and social functioning given the variability in findings across studies (Klin et al., 2002; Poon et al., 2012; Rice et al., 2012; Sasson et al., 2008; Unruh et al., 2016; van Rijn et al., 2019).

Table 1 Participant Characteristics

Characteristic	ASD group (n=37)			TYP group (n=30)		
Gender						
Male	33			20		
Female	4			10		
	Mean	SD	Range	Mean	SD	Range
Age in years	8.06	2.42	3–12	7.41	2.63	3–12
Nonverbal IQ[a]	97.24	14.59	68–129	116.04**	12.94	97–151
SRS-2 Mean T-Scores[b]						
Total	77.57	9.36	58–90	46.32**	7.32	36–64
SCI	76.38	9.52	56–90	46.04**	7.21	35–62
RRB[1]	77.89	9.21	48–90	47.79**	9.00	40–80
ADOS-2 CSS						
Total	7.51	1.52	5–10	-	-	-
SA	7.54	1.83	3–10	-	-	-
RRB[2]	7.22	1.89	1–10	-	-	-

ASD, autism spectrum disorder; TYP, typically developing; SRS-2, social responsiveness scale – second edition; SCI, social communication and interaction; RRB[1], restricted interests and repetitive behaviours; ADOS-2, autism diagnostic observation schedule – second edition; CSS, calibrated severity score; SA, social affect; RRB[2], repetitive and restricted behaviours.

[a] Nonverbal IQ scores from the Leiter-3 for participants with ASD (n = 33) and TYP participants (n = 23). [b] SRS-2 Mean T-Scores for participants with ASD (n = 37) and TYP participants (n = 28).

** Indicates a significant group difference at $p < .001$.

Methods

Participants

Participants were 67 children; 37 children diagnosed with ASD and 30 TYP children, aged 3–12 years (ASD: $M = 8.06$, $SD = 0.40$; TYP: $M = 7.41$, $SD = 0.48$). Similar to previous studies (DiCriscio et al., 2016; Harrison & Slane, 2020) a broad age range was selected in consideration of the characteristic persistent influence of CIs and reduced attention allocation to social stimuli throughout development in ASD (Frazier et al., 2017; Manyakov et al., 2018). There was no significant difference in age between groups (t = -1.06, $p = .295$), however a trend in the distribution of male and female participants was observed, with 66.7% and 89.2% male participants in the TYP and ASD groups, respectively, χ^2 (1, 67) = 3.813, $p = .051$, $phi = 0.024$. Participant characteristics are presented in Table 1.

Participants were recruited through the Clinic for Autism and Neurodevelopmental Research (CAN Research) located at the Brain and Mind Centre, within The University of Sydney. Study eligibility of participants with an ASD diagnosis was confirmed using the Autism Diagnostic Observation Schedule - Second Edition (ADOS-2; Lord C., 2012), administered by research-reliable assessors. Individuals with severe renal, hepatic, cardiovascular or respiratory illness were excluded from the study. Recruitment of TYP participants occurred through locally distributed flyers and by word-of-mouth. Exclusion criteria for TYP participants included neurodevelopmental or mental health diagnoses (e.g., anxiety, depression, ASD, sensory processing disorder) and severe physical illnesses (e.g., severe cardiac, hepatic, renal, respiratory illness).

Once enrolled, all participants were administered the Leiter-3 (Roid et al., 2013), a nonverbal cognitive assessment, and caregivers completed the Social Responsiveness Scale - Second Edition (SRS-2; Constantino & Gruber, 2012) as a global measure of social functioning. The research project was approved by the Human Research Ethic Committee (HREC) of The University of Sydney (references 2013/502, 2013/341), and informed consent was obtained from caregivers prior to study enrolment.(Table 1 top)

Measures

Autism Diagnostic Observation schedule – Second Edition (ADOS-2; Lord C., 2012)

The ADOS-2 is a semi-structured, play-based observational measure of common autism symptoms, which fall under the broad domains of Social Affect (SA; including communication, social interaction, and play-based behaviours) and Repetitive and Restricted Behaviours (RRB; including unusual sensory interests, aggressive and stereotyped behaviours) (Lord et al., 2012). Modules 1 ($n = 13$), 2 ($n = 15$) or 3 ($n = 9$) were administered based on participant age and expressive language level. As a standardised measure of core symptom severity, total and domain calibrated severity scores (CSS), ranging from 1 to 10, were calculated, with

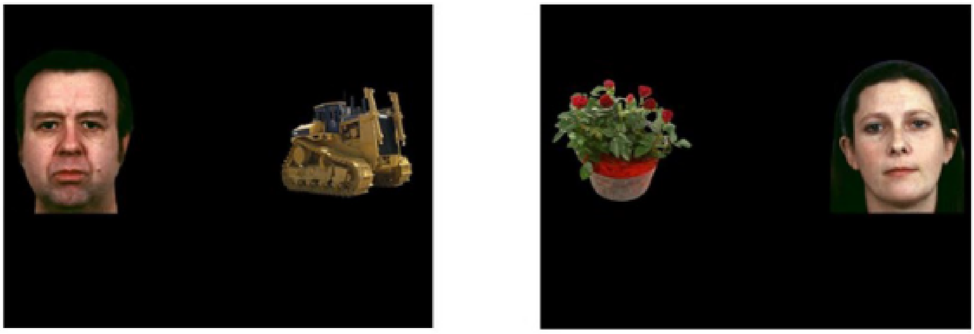

Fig. 1 **Example images from the visual preference task developed by Sasson and Touchstone (2014).** (A) Image of a face paired with a HAI; (B) Face paired with a LAI. HAI, high autism interest; LAI, low autism interest

higher scores indicating greater symptom severity (Gotham et al., 2009).

Leiter International Performance Scale - Third Edition (Leiter-3; Roid et al., 2013)

Designed for assessment of individuals between 3 and 75 years of age, the Leiter-3 is a nonverbal intellectual assessment commonly administered to ASD populations (Roid & Koch, 2017). It comprises 10 subtests which measure cognitive ability across three dimensions, including general IQ, nonverbal memory and processing speed (Roid & Koch, 2017).

Social responsiveness scale – Second Edition (SRS-2; Constantino & Gruber, 2012)

The SRS-2 is a 65-item informant-completed rating scale of socially relevant behaviours in ASD that includes both preschool (2:6 to 4:6 years) and school-age (4:0–18:0 years) forms that can be rated by parents and teachers. Items are summed to calculate scores in the domains of Restricted Interests and Repetitive Behaviour (RRB) and Social Communication and Interaction (SCI), which combine to an overall Total Score (Constantino & Gruber, 2012). Results are reported as T-scores, with scores above 75 indicating severe social deficits, scores between of 66 to 75 considered moderate, scores of 60 to 65 considered mild, and scores below 60 indicate no socially challenged behaviour related to ASD (Bruni, 2014).

Eye-Tracking Task

The current study employed the visual preference task developed by Sasson & Touchstone (2014; Fig. 1). The HAI and LAI objects used in this task were previously validated to be of CI and non-CI interest, respectively, across childhood (South et al., 2005). Participants were presented with one block of 20 randomly presented slides of a social image (a face) paired with a HAI (i.e., CI) or LAI object. Neutral, happy, sad, angry, and fearful emotional expressions were each presented four times. Social and object images did not repeat, and their location was counterbalanced between the right and left sides of the screen. Participants sat on a booster chair fitted on a regular office chair, or a regular height-adjustable office chair, and were positioned approximately 65 cm away from a 23-inch computer monitor with a pixel resolution of 1920 × 1080. The monitor was integrated with the Tobii TX300 eye tracker (Tobii Technology, Stockholm, Sweden), which was used to collect eye tracking data with a sampling rate of 300 Hz and spatial accuracy of 0.4 degrees.

Participants completed a 9-point calibration procedure. Once calibration was successfully completed, participants were told they would be looking at some pictures and could look wherever they wanted. Prior to the first paired social and object image slide being presented, an introductory slide reading "Hi, let's start" was presented to orient attention to the screen. A slide reading "You're doing really well" was presented half-way through the task to maintain attention to the screen, and a final slide reading "Well done! You're finished" marked the end of the task. The presenter would read aloud these written prompts as each of these slides were presented to reinforce and tailor the message for participants who were illiterate. Each slide was presented for 5 s, followed by an interstimulus interval (ISI) of an animated figure presented centrally for 500ms to encourage task engagement. The total duration of the task was approximately 1 min and 20 s.

An I-VT filter was applied to raw data, using a velocity threshold of 30 degrees/second and a minimum fixation duration of 60ms (Tobii Technology AB, 2016). Areas of Interest (AOIs) were drawn around each face and object image. Face and object AOIs approximated 15% and 12% of the screen, respectively. Eye tracking variables were aggregated using Tobii Studio Version 3.4.8 (Tobii Technology AB, 2016). Overall, 20 participants did not have eye tracking data collected. Technical issues prevented task administration for 16 participants and calibration could not be completed with four participants due to noncompliance. The data from an additional two participants were excluded from analyses as the quality of their gaze data fell below the 20% threshold adopted in this study, and used in prior studies (for example, Harrop et al., 2018a).

(Fig. 1 top)

Data Analysis

Similar to previous studies employing this task (Harrop et al., 2018a; Sasson & Touchstone, 2014; Unruh et al., 2016), the following dependent variables (DVs) were analysed as measures of social and object attention: (1) Prioritisation, the latency to first fixate to the face or object; (2) Preference, the proportion of total fixation duration to the face or object relative to total fixation duration to the AOIs on the screen; and (3) Duration, the total fixation duration to the face or object across all trials.

Initial exploratory analyses indicated a non-normal distribution of data for the prioritisation DV only; log transformations were therefore performed, although significant improvements in normality were not observed. As subsequent non-parametric and parametric analyses yielded similar results, parametric results are reported.

Repeated-measures analyses of variance (RM-ANOVAs) were conducted on each DV with object type (HAI, LAI) as the within-group variable, and diagnosis (ASD, TYP) as the between-group variable. Greenhouse-Geisser corrections were applied as the assumption of sphericity was violated.

Exploratory analyses using Spearman's rank order correlations were conducted between eye-tracking DVs and the ADOS-2 CSS for Total, SA and RRB domains, and with the SRS-2 Total, SCI and RRB domain T-scores. Data were analysed using IBM SPSS Version 26® (IBM Corp, 2019).

Results

Preliminary analysis on effect of sex, age, and non-verbal IQ

Given the proportion of male and female participants across both groups, separate univariate analyses of variance (ANOVAs) with sex as the between-subjects factor were conducted on each DV (prioritisation, preference, duration) within both groups. These analyses confirmed no significant effect of sex on any eye-tracking DV within the ASD group ($p \geq .271$ for all analyses). Likewise, within the TYP group, there was no significant effect of sex on eye tracking variables ($p \geq .070$). Age was not included as a covariate due to non-significant differences in mean ages between groups and analyses of scatterplots indicated that the assumption of linearity between age and eye-tracking DVs was not met. Similarly, non-verbal IQ was not included as a covariate as correlational analyses indicated no significant associations with any eye-tracking DV across ASD or TYP groups. Although eligibility criteria did not exclude individuals with lower IQs, only two participants scored below 70 for non-verbal IQ, precluding analysis of differences in gaze behaviour based on this characteristic. Analyses were conducted with and without these participants and the pattern of results remained the same, hence results are reported inclusive of these participants.

Group differences in eye-tracking variables

PrioritisationFaces Results from a 2×2 RM-ANOVA indicated no significant object type x diagnosis interaction effect, $F(1,64)=1.799$, $p=.354$, $\eta^2_p = 0.013$. There was a significant main effect of object type, $F(1, 65)=8.841$, $p=.004$, $\eta^2_p = 0.120$, and a significant main effect of diagnosis, $F(1,65)=7.526$, $p=.008$, $\eta^2_p = 0.104$, with the ASD group taking longer to look to the face compared to the TYP group ($M_{diff} = 0.557$, $SE=0.203$, $p=.008$). Group differences for each object type are illustrated in Fig. 2. Post-hoc analyses revealed that both ASD and TYP took longer to prioritise the face when paired with an HAI compared to LAI object (ASD: $M_{diff}=0.305$, $SE=0.137$, $p=.033$; TYP: $M_{diff}=0.159$, $SE=0.037$, $p<.001$).

Objects A 2×2 RM-ANOVA revealed no significant object type x diagnosis interaction effect $F(1,65)=2.425$, $p=.124$, $\eta^2_p = 0.036$. There was a significant main effect of object type $F(1,65)=23.916$, $p<.001$, $\eta^2_p = 0.269$. Pairwise comparisons demonstrated that both groups fixated faster to HAI compared to LAI objects ($M_{diff} = 0.314$, $SE=0.064$, $p<.001$). A trend for the main effect of diagnosis, F(1,

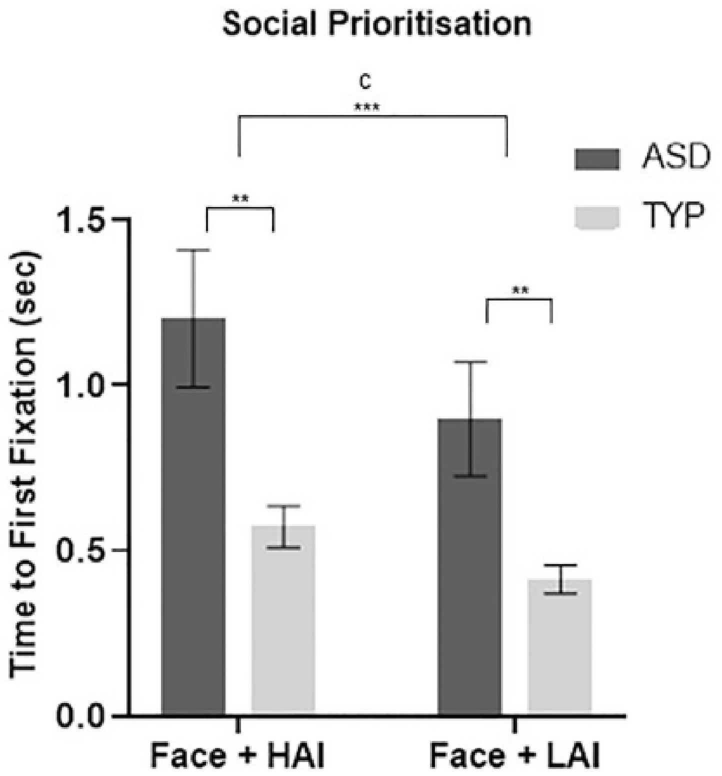

Fig. 2 Mean (+/- standard error) time to first fixation in seconds to faces adjacent to HAI and LAI objects in ASD and TYP groups. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.
*** $p<0.001$. ** $p<.05$

65) = 3.938, $p=.051$, $\eta^2_p = 0.057$, indicated the TYP group may have prioritised objects faster than the ASD group ($M_{diff} = 0.393$, $SE = 0.198$, $p=.051$). (Fig.

2 top)

PreferenceFaces A 2×2 RM-ANOVA demonstrated a significant object type x diagnosis interaction effect, F(1,65) = 6.018, $p=.017$, $\eta^2_p = 0.085$ (see Fig. 1 A of Supplementary Information, SI). Significant main effects were found for both object type F(1,65) = 112.397, $p<.001$, $\eta^2_p = 0.634$ and diagnosis F(1,65) = 5.588, $p=.021$, $\eta^2_p = 0.079$. Group differences for both object types are shown in Fig. 3. Overall, the TYP group demonstrated greater preference for faces regardless of object type ($M_{diff} = 0.094$, $SE = 0.031$, $p=.005$). Both groups displayed less preference for the face when paired with HAI compared to LAI objects ($M_{diff} = 0.111$, $SE = 0.013$, $p<.001$). Follow up analyses indicated that the interaction effect was driven by the TYP group spending significantly more time fixating on faces during HAI trials than the ASD group ($p=.001$), while no significant group difference was evident during LAI trials ($p=.241$).

Objects A 2×2 RM-ANOVA resulted in a significant object type x diagnosis interaction effect, F(1,65) = 6.018, $p=.017$, $\eta^2_p = 0.085$ (Fig. 1B of SI), with follow up analyses indicating the ASD group had a significantly greater preference

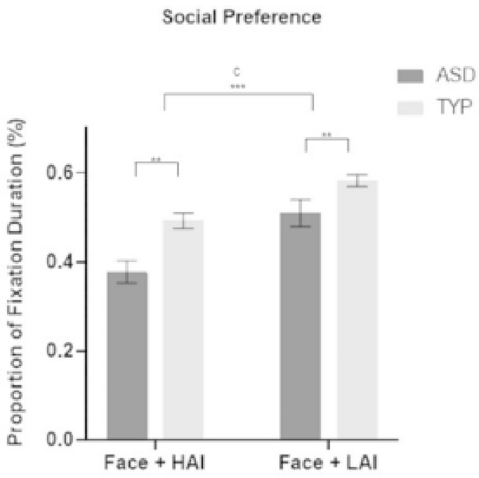

Fig. 3 Mean (+/- standard error) proportion of fixation duration in seconds to faces adjacent to HAI and LAI objects in ASD and TYP groups. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.
*** $p<.001$. ** $p<.05$.

for HAI objects compared to the TYP group, ($p=.001$) while there was no group difference in the preference for LAI objects ($p=.214$). Pairwise comparisons revealed an overall higher preference to view objects in the ASD group ($M_{diff}=7.047$, $SE=2.981$, $p=.021$), while both groups had a preference to view HAI over LAI objects ($M_{diff}=13.568$, $SE=1.280$, $p<.001$). (Fig. 3 top)

Duration

Faces A 2×2 RM-ANOVA revealed no significant interaction effects, $F(1,65)=3.144$, $p=.081$, $\eta^2_p=0.046$. Significant main effects were demonstrated for both object type, $F(1,65)=44.013$, $p<.001$, $\eta^2_p=0.404$, and diagnosis, $F(1,65)=44.581$, $p<.001$, $\eta^2_p=0.407$. Pairwise comparisons indicated shorter fixation durations to faces in the presence of HAI objects for both groups ($M_{diff}=2.672$, $SE=0.405$, $p<.001$), and the TYP group demonstrated longer fixation durations to faces compared to the ASD group ($M_{diff}=8.944$, $SE=1.375$, $p<.001$).

Objects There was no significant object type x diagnosis interaction for the duration of fixations to objects, $F(1,64)=2.404$, $p=.126$, $\eta^2_p=0.036$. Significant main effects for object type, $F(1,65)=44.013$, $p<.001$, $\eta^2_p=0.404$, and diagnosis, $F(1,65)=44.581$, $p<.001$, $\eta^2_p=0.407$ were found. Pairwise comparisons revealed greater fixation durations to HAI compared to LAI objects for both groups ($M_{diff}=2.676$, $SE=0.403$, $p<.001$), and the TYP group displayed greater fixation durations to both object types compared to the ASD group ($M_{diff}=9.064$, $SE=1.358$, $p<.001$). Figure 4 illustrates group differences in fixation duration to both faces and objects.

The means and standard deviations of eye-tracking DVs are detailed in Table 1 of Supplementary Information (SI).
(Fig. 4 top)

Correlations between eye-tracking variables and clinical measures

Within the ASD group, there were significant medium sized negative correlations between ADOS-2 CSS RRB scores and fixation duration to faces across object types ($\rho=-0.339$, $p=.040$), and fixation duration to faces adjacent to LAI objects ($\rho=-0.401$, $p=.014$), indicating that greater attention to faces overall and in the presence of LAI objects, was associated with a lower severity of restricted and repetitive behaviours. A similar correlation was not found for faces adjacent to HAI objects. One additional statistically significant correlation between ADOS-2 Total CSS and fixation duration to HAI objects ($\rho=-0.335$, $p=.043$) was found, suggesting greater symptom severity was associated with less attention to HAI objects.

Baseline significant differences in Total, SCI and RRB domain scores of the SRS-2 demonstrated greater impairment in the ASD compared to the TYP group across all three domains. For the ASD group, significant medium sized negative correlations between fixation duration to LAI objects and RRB ($\rho=-0.343$, $p=.038$), SCI ($\rho=-0.353$, $p=.032$) and Total scores ($\rho=-0.360$, $p=.029$) demonstrated that greater attention to LAI objects was associated with higher functioning overall and in behaviours related to social communication and interaction skills, and repetitive behaviours and restricted interests. No significant correlations between attention measures and SRS-2 scores were found for HAI objects or the TYP group. See SI for correlational analyses between eye-tracking DVs and ADOS-2 and SRS-2 scores for the ASD group.

Discussion

Using an established visual preference eye-tracking task, the purpose of this study was to investigate the contextual influence of circumscribed interests (CIs) on patterns of social and object attention in children with ASD and their TYP

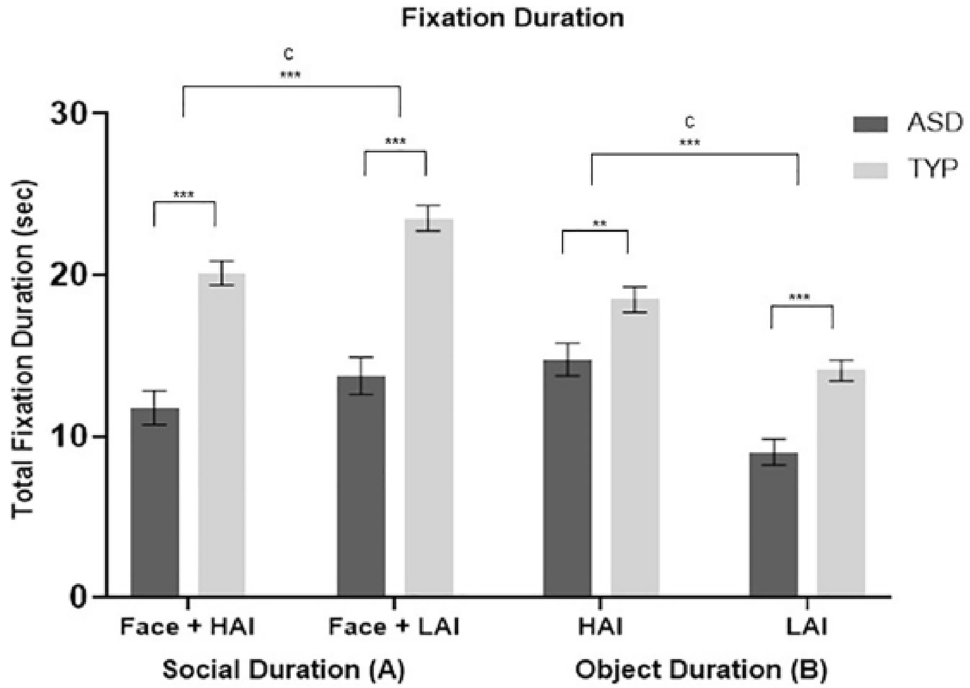

Fig. 4 Mean (+/- standard error) total duration of fixations to face and object stimuli in ASD and TYP groups. (A) Total fixation duration to face adjacent to HAI and LAI objects. (B) Total fixation duration to HAI and LAI objects. ASD, autism spectrum disorder; TYP, typically developing; HAI, high autism interest; LAI, low autism interest; C, condition effect.
*** $p<.001$. ** $p<.05$.

peers, and the relationship between these patterns and social functioning more broadly. In support of our first hypothesis, results demonstrated reduced attention to social stimuli in children with ASD compared to TYP children, regardless of the presence of HAI objects (representing CIs). Reduced attention in the ASD group also extended to non-social stimuli, a surprising finding of the study. Analysis of attention patterns indicated that both ASD and TYP groups appeared to be influenced by CIs. That is, both groups exhibited reduced social attention and increased non-social attention in the presence of CIs, in line with our second hypothesis. Among participants with ASD, correlational analyses indicated that greater attention to faces overall and in the presence of LAI objects was related to less severe restricted and repetitive behaviours as measured by the ADOS-2, while greater fixation duration to LAI objects was significantly associated with greater social functioning, as measured by the SRS-2.

Reduced social attention was evident in children with ASD across all three attention measures. Overall, children with ASD were significantly slower in prioritising the face; similarly, their preference to attend and maintain attention to faces was significantly reduced compared to TYP children across object types. Although the contextual influence of CIs did influence the preference to attend to faces in the current study, this finding did not extend to the social prioritisation and duration of attention variables. These results contrast with Sasson & Touchstone (2014) where reduced social attention in pre-schoolers with ASD was only evident when paired with objects related to CIs (i.e., HAIs). The specific influence of CIs on social prioritisation, preference and duration variables led to their conclusion that social attention is influenced by the nature of stimuli competing for attention in this population, rather than a global social saliency deficit as postulated by the social motivation hypothesis (Sasson & Touchstone, 2014). However, the broader reductions in social attention patterns in children with ASD demonstrated in this study are supportive of more recent studies (Harrison & Slane, 2020; Mo et al., 2019; Unruh et al., 2016), and meta-analytic findings of atypical gaze patterns towards social stimuli (Chita-Tegmark, 2016; Frazier et al., 2017), supporting overall reductions in social attention irrespective of the salience of competing stimuli.

Surprisingly, object-directed attention mirrored social attention patterns across both groups of participants. The overall duration of attention to both object types was reduced in children with ASD. Although decreased attention to LAI objects could be reasonably expected (Anderson et al., 2006; Sasson et al., 2011), the finding of overall decreased attention to HAI objects is interesting considering the breadth of literature supporting the increased salience of CIs in this population (Harrop et al., 2018a; Manyakov et al., 2018; Sasson et al., 2011; Sasson & Touchstone, 2014; Traynor et al., 2019; Unruh et al., 2016). A similar trend was observed for the prioritisation of objects, with the TYP group taking a significantly shorter amount of time to fixate to either object type, a result consistent with the other main findings of this study. Reduced object-directed attention in ASD has been reported cross-modally (Keehn et al., 2016, 2017; Parsons et al., 2017). In eye-tracking for example, Parsons et al., (2017) investigated the distribution of attention to object and social stimuli in infants at high and low familial risk of ASD and found that high risk infants later diagnosed with ASD engaged less with objects and this was associated with poorer future vocabulary skills. Supporting this, neurophysiological and neurological evidence of under-reactivity or hypoactivation of attentional networks in response to both social and object stimuli has been replicated across studies, suggesting that differences in attention across social and non-social domains may be implicated in ASD (Clements et al., 2018; Dichter et al., 2010; Keehn et al., 2016, 2017; Richey et al., 2014).

An increased influence of CIs in the attentional patterns of children with ASD was evident in the reduced preference to attend to faces and increased preference to attend to HAI objects in that condition. This finding, which extends the results of Sasson & Touchstone (2014) in toddlers to a broader age cohort across childhood in ASD, suggests that CIs core to ASD do elicit a relative preference to attend to HAI stimuli. However, in this study the influence of CIs was shared across groups with both ASD and TYP children spending less time looking at faces and more time looking at HAI objects. Similarities in the influence of CIs on attention patterns across ASD, TYP and Broad Autism Phenotype (BAP) groups have also been reported in other studies (Goldberg et al., 2017; Morrison et al., 2018; Sasson et al., 2008; Silver et al., 2020). A recent study by Silver et al., (2020), investigated whether children and adults with ASD demonstrated an advantage in the visual processing of CIs and found no differences between ASD and TYP groups in the early visual perception of CIs, but surmised these interests may interfere with later processing streams involved in cognitive control and arousal. These findings also raise questions regarding the contexts and cognitive mechanisms subserving the influence of CIs on atypical attention processes specifically, and socio-cognitive processes and social functioning more generally, in ASD.

The shared influence of CIs across groups and attention variables, and overall reduced attention patterns in the ASD group may also be suggestive of a conceptual and neurocognitive divergence in gaze behaviour to social and CI-related stimuli. Recent studies in both children and adults with ASD and their neurotypical peers have demonstrated that an increased preference for HAI objects was not due to an avoidance of social stimuli (Gale et al., 2019; Manyakov et al., 2018), contributing to the possibility that the increased salience of CIs is conceptually and operationally distinct from the salience of social stimuli such as faces (Bottini, 2018).Although not the focus of this study, abnormalities in the early development and regulation of attentional control and disengagement behaviours have led some researchers to hypothesise a different conceptual framework for understanding shared arousal mechanisms concurrent with atypical attention disengagement and attention shifting mechanisms between social and non-social stimuli in ASD (Keehn et al., 2013). While altered visual processing mechanisms may lead to an overall reduction in attention in ASD (Bellocchi et al., 2017), as seen in this study, the increased salience of CIs under some conditions may partly explain the heterogeneity reported across different studies, providing further impetus for employing multimodal methods investigating underlying neurocognitive process in CI-related visual attention patterns across neurodevelopmental and typically developing cohorts.

In the current study, increased attention allocation to faces overall, and adjacent to LAI objects, was associated with reduced symptom severity in restricted and repetitive behaviours. Furthermore, greater attention to LAI objects directly was associated with higher social skills and milder restricted and repetitive behaviours in children with ASD. While these results appears to be in contrast with previous research highlighting a positive association between social impairment and object-directed attention (Klin et al., 2002; Pierce et al., 2016; Rice et al., 2012), they could potentially reflect that greater task engagement is associated with better social functioning. A similar conclusion was drawn in a social skills intervention study with findings suggesting that higher social functioning in individuals with ASD was associated with increased attention to faces and background objects (Greene et al., 2020). Neurologically, the under-reactivity of biomarkers of arousal and attention has also been associated with atypical attention to behaviourally relevant social and non-social stimuli and ASD symptomatology (Bottini, 2018; Keehn et al., 2016, 2017), providing additional support for the suggestion that both social and non-social visual attention processes may play a complementary role in the social communication and functioning challenges commonly found in individuals with ASD. Due to the small sample size and exploratory nature of the correlational analyses in this study, results should be interpreted with caution and require replication. However, in the future, a larger study investigating task orientation and engagement as a predictor of social functioning and repetitive and restricted behaviours may reinforce some the clinical associations found in this study and disentangle some of the existing heterogeneity in this research area.

There are several other limitations in the present study that warrant consideration. Due to a relatively small sample size, within- and between-group sex differences in social and object attention patterns could not be investigated. As most of the participants in the ASD group were male, and previous research has evidenced similarities in social attention patterns in the presence of CIs in female participants with and without ASD (Harrop et al., 2018a, b), the results of this study may be more applicable to males. Second, the visual preference task administered included object AOIs which shared a relatively smaller proportion of the screen compared to face AOIs. Hence, it is possible that perceptual differences biased differences in attention patterns to social and non-social stimuli, cautioning interpretation of any main effects of object type. As the aim of this study was to investigate the influence of CIs on social and non-social attention patterns, the task was not suited to determine overall reductions in attention. Future studies could incorporate task paradigms designed to probe overall changes or reductions in attention across groups. Additionally, the type of CIs used may have influenced the attention patterns reported in this study. Although the CIs used in this task have been validated across childhood in ASD (South et al., 2005), gender differences in CIs (Harrop et al., 2019; Nowell et al., 2019), and the use of personalised over non-personalised CIs (Harrison & Slane, 2020; Traynor, 2019), have previously been shown to influence social attention patterns in ASD cohorts. The growing number of studies in this area of research suggests a systemic review on the influence of CIs on social attention patterns across childhood in ASD is warranted.

The results of the current study contribute to a growing body of evidence of atypical attention patterns to both social and object stimuli, supportive of the hypothesis that attention atypicalities demonstrated in ASD extend beyond the social domains suggested by the social motivation hypothesis (Bottini, 2018; Chevallier et al., 2012; Clements et al., 2018; Keehn et al., 2016). The results may also suggest that objects common to CIs in children with ASD may play a more general role in influencing their attention patterns and those of their typically developing peers. Indeed, attention to behaviourally or task-relevant stimuli including both social and non-social content may be more instrumental in the day-to-day social and adaptive challenges experienced by children with ASD than is currently understood. Specific to CIs, future cross-modal research, implementing static, as well as dynamic and interactive task paradigms (e.g., Chevallier et al., 2015) may also facilitate a deeper understanding of the operational influence of CIs on early and later stage socio-cognitive processes and how this may change over the course of childhood. Developing a deeper and more robust model of contextual variations to attention patterns throughout development would contribute to our overall understanding of this important behavioural phenotype, and to future research investigating the implications of atypical gaze behaviour in the diagnosis and treatment response of children with ASD.

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Conflict of interest Professor Ian Hickie was an inaugural Commissioner on Australia's National Mental Health Commission (2012-18). He is the Co-Director, Health and Policy at the Brain and Mind Centre (BMC) University of Sydney. The BMC operates an early-intervention youth services at Camperdown under contract to headspace. Professor Hickie has previously led community-based and pharmaceutical industry-supported (Wyeth, Eli Lily, Servier, Pfizer, AstraZeneca) projects focused on the identification and better management of anxiety and depression. He was a member of the Medical Advisory Panel for Medibank Private until October 2017, a Board Member of Psychosis Australia Trust and a member of Veterans Mental Health Clinical Reference group.Ethics approval: All research was conducted in accordance with the 1964 Declaration of Helsinki, Good Clinical Practice (GCP) guidelines, institutional and national standards in the conduct of human research. The study was approved by the Human Research and Ethics Committee (HREC) of The University of Sydney, Reference numbers: 2013/502, 2013/341.Consent Written informed consent was obtained from a primary caregiver of each participant involved in the study.Authors' contribution: ZA was involved in ADOS administration and scoring, and was responsible for data collection, cleaning, analysis, and drafting of the manuscript. KAB contributed to data analysis and manuscript review. RT contributed to data collection. EET was involved in ADOS administrating and scoring. NJS provided the task paradigm and contributed to manuscript review. IBH aided in study implementation. AJG led experimental design conceptualisation, contributed to participant recruitment and study implementation, data analysis methods and reviewing the drafted manuscript.

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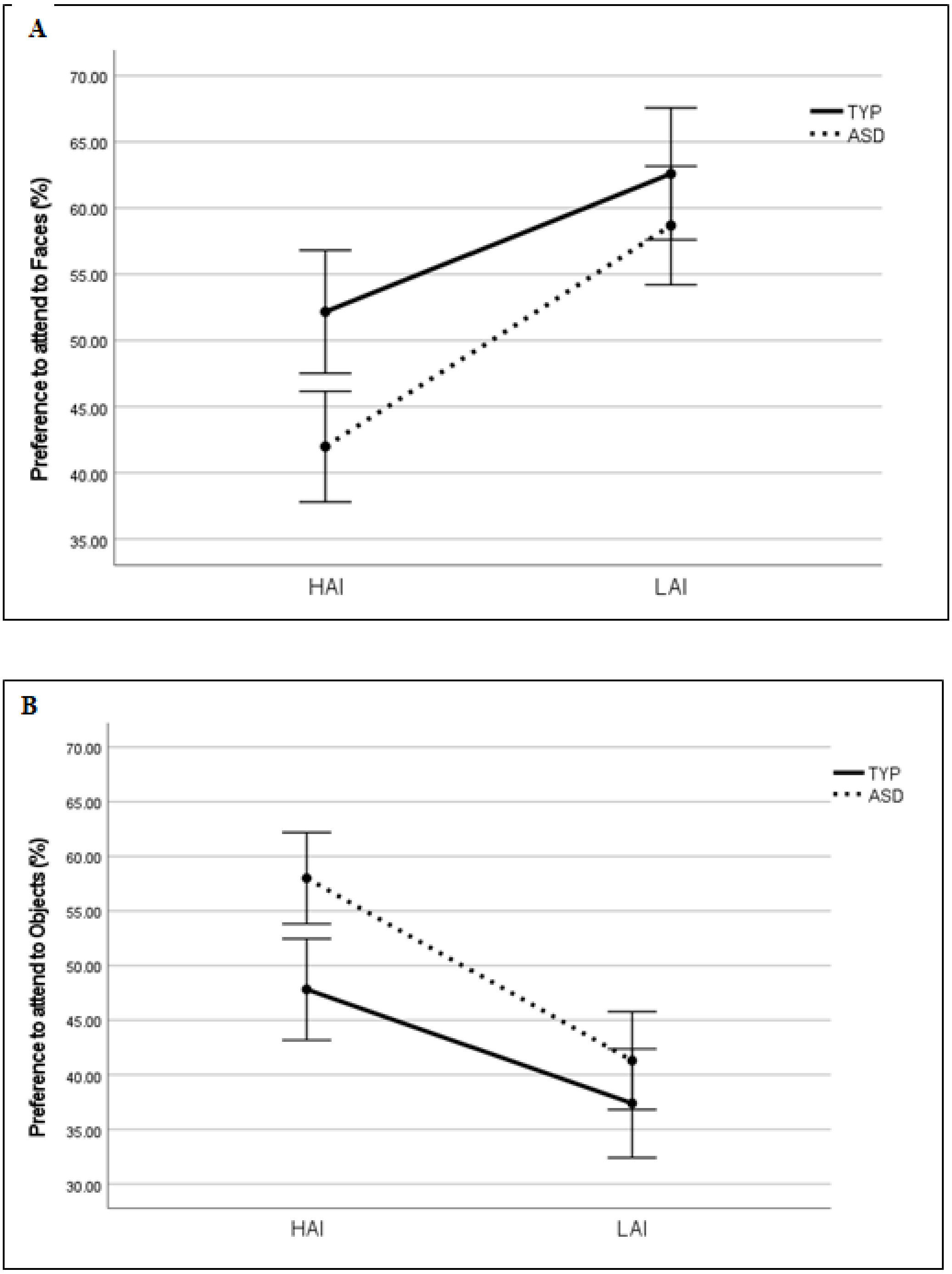
8. Appendix B: Chapter 2 Supplementary Material

Supplementary Information

Figure 1 Estimated marginal means for preference to attend to faces (A) and objects (B) under High Autism Interest (HAI) and Low Autism Interest (LAI) object conditions.



9. Appendix C: Chapter 3 Scripts for SBR videos

***If you give a cat a cupcake* Script**

(Presenter holds book next to face with front of book towards camera)

[Introduction] "This book is called *If you give a cat a cupcake*. Written by Laura Numeroff and illustrated by Felicia Bond". *(look at camera during Intro, turn 3 pages)*

[Book, p.5] If you give a cat a cupcake, *(turn page)*

[Book, p.6] he'll ask for some sprinkles to go with it.

[Book, p.7] When you give him the sprinkles, he might spill some on the floor.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to sprinkles, then back to presenter and book

[ETC, p. 7] "Look at all the sprinkles!"

*(look at camera during ETC, look & **point** to sprinkles, look to camera, turn page)*

[Book, p.8] Cleaning up will make him hot, so you'll give him a bathing suit

[Book, p.9] and take him to the beach.

Camera focuses solely on presenter during ETQ below with background objects in view, then back to book and presenter as presenter turns page

[ETQ, p. 9] "Do you like going to the beach?"

(look at camera during ETQ, wait, turn page)

[Book, p.10] He'll want to go in the water

[Book, p.11] and build a sandcastle, too.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to girl in sandcastle, then back to presenter and book

[ETC, p. 11] "The girl is in the sandcastle!"

*(look at camera during ETC, look & **point** to girl, look to camera)*

[Book, p. 11 cont'd] Then he'll look for seashells. *(turn page)*

[Book, p.12] He'll find a few other things as well.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to surfboard, then back to presenter and book

[ETQ, p. 12] "Will he find the surfboard?"

*(look at camera during ETC, look & **point** to surfboard, look to camera)*

[Book, p.13] He'll put them in his pail and try to pick it up, but it'll be too heavy. He'll decide he needs to work out at the gym. *(turn page)*

[Book, p. 14] First he'll warm up on the treadmill. Then he'll lift a weight or two.

[Book, p.15] He might even try a karate class. *(turn page)*

[Book, p.16] After the gym, he'll want to go to the park. When you get there, he'll see the rocks. He'll climb as high as he can go.

[Book, p.17] At the top, he'll see the lake. He'll want you to take him rowing.

Camera focuses briefly on presenter and presenter during ETQ below, then zooms in on both pages during gestural point to rowboats, then back to presenter and book

[ETQ, p. 17] "Which rowboat will he choose?"

*(look to camera during ETQ, look & **point** to rowboats, look to camera, turn page)*

[Book, p. 18] He'll be the captain, and you'll have to row.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to girl's face while rowing, then back to presenter and book

[ETC, p.18] “Rowing looks really hard”

*(look at camera during ETC, look & **point** to girl’s face while rowing, look to camera)*

[Book, p.19] Then he’ll notice the merry-go-round and want to go for a ride.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to cat, then back to presenter and book

[ETQ, p.19] “Is he excited?”

*(look at camera during ETQ, look & **point** to cat, look to camera, turn page)*

[Book, p.20] He’ll want you to go for a ride, too. You’ll choose the horse with the purple mane, and he’ll get on the whale.

[Book, p.21] The whale will remind him of the science museum. He’ll ask you to take him there. First he’ll find the…. *(turn page)*

[Book, p.22] …dinosaurs.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to cat, then back to presenter and book

[ETQ, p. 22] “Which dinosaur is he looking at?”

*(look at camera during ETQ, look & **point** to cat, look to camera)*

[Book, p.23] Then he’ll visit the… *(turn page)*

[Book, p. 24] Hall of Apes.

[Book, p. 25] When the museum closes, you’ll be the last to leave. *(turn page)*

[Book, p.26] On the way home, you’ll pass by the beach. You’ll help him gather all of his things.

[Book, p.27] Then he’ll want to race you.

[Book, p. 28] When you get home, he'll empty the sand from his shoes. He might spill some on the floor.

Camera focuses on both presenter and book during ETC below, then zooms in on both pages during gestural point to sand on floor, then back to presenter and book

[ETC, p. 28] "Look at the mess he's making!"

(look at camera during ETC, look & ***point*** *to sand falling on floor, look to camera)*

[Book, p. 29] Seeing the sand on the floor will remind him of the sprinkles. He'll probably ask you for some. *(turn page)*

[Book, p. 30] And chances are,

[Book, p. 31] if you give him some sprinkles, *(turn page)*

[Book, p. 32] he'll want a cupcake to go with them.

Camera focuses solely on presenter during ETQ below with background objects in view

[ETQ, p. 32] "Do you like cupcakes?" *(look to camera during ETQ, wait)*

[ETC] "I do!"

[End] "And that's the end of the story"

If you give a dog a donut **Script**

(Presenter holds book next to face with front of book towards camera)

[Introduction] "This book is called *If you give a dog a donut*. Written by Laura Numeroff and illustrated by Felicia Bond". *(look at camera during Intro, turn 3 pages)*

[Book, p. 5] If you give a dog a donut, *(turn page)*

[Book, p. 6] he'll ask for some apple juice to go with it.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to dog, then back to presenter and book

[ETC, p.6] "He's got 2 donuts!"

(look at camera during ETC, look & ***point*** *to dog, look back at camera, turn page)*

[Book, p. 7] When you give him the juice, he'll drink it all up.

[Book, p. 8] Then he'll ask for more. There won't be any left, so he'll want to make his own.

Camera focuses on presenter and books during ETQ below, then zooms in on both pages during gestural point to dog, then back to presenter and book

[ETQ, p. 8] "Is he upset there's no more juice?"

(look to camera during ETC with upset face, look & ***poin****t to dog's face, back to camera)*

[Book, p.9] He'll go outside to pick apples.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to skateboard, then back to presenter and book

[ETC, p. 9] "He's riding a skateboard!"

(look at camera during ETQ, look & ***point*** *to skateboard, look to camera, turn page)*

[Book, p. 10] When he's up in the tree, he'll toss you one. Throwing the apple will make him think of baseball.

[Book, p. 11] He'll want to play.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to boy, then back to presenter and book

[ETQ, p. 11] Will he catch the apple?"

*(look at camera during ETC, look & **point** to boy, look to camera, turn page)*

[Book, p. 12] You'll have to get a ball…

[Book, p. 13] and a glove. *(turn page)*

[Book, p. 14] Of course, he'll also need a bat.

[Book, p. 15] He'll ask you to pitch.

Camera focuses solely on presenter during ETQ below with background objects in view, then back to book and presenter as presenter turns page

[ETQ, p. 15] "Have you played baseball before?"

(look at camera during ETQ, wait, turn page)

[Book, p. 16] He'll hit a home run!

[Book, p. 17] *(turn page)*

[Book, p. 18] Then he'll do a happy dance to celebrate.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to happy face of dog, then back to presenter and book

[ETC, p. 18] "He's very happy "

*(look at camera during ETC, **point** to happy faces of dog, look to camera)*

[Book, p. 19] *(turn page)*

[Book, p. 20] Dancing will make him hot and dusty, so he'll need some water. He'll probably start a water fight.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to boy covering eyes, then back to presenter and book

[ETC, p. 21] "The boy is getting wet!"

*(look at camera during ETC, look & **point** to boy covering eyes, look to camera)*

[Book, p. 21] You'll have to dry him off with your bandanna. *(turn page)*

[Book, p. 22] He'll wrap it around his head and pretend that he's a pirate.

[Book, p. 23] Then he'll want to go on a treasure hunt.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to focus of dog's attention, then back to presenter and book

[ETQ, p. 23] "What do you think he'll find?"

*(look at camera during ETQ, look & **point** to focus of dog's attention, look to camera, turn page)*

[Book, p. 24] He'll find an old kite and want to make one himself.

[Book, p. 25] You'll have to get him some sticks, paper, and string. *(turn page)*

[Book, p. 26] When the kite is finished,

[Book, p. 27] he'll want to fly it. It will go higher and higher, *(turn page)*

[Book, p. 28] until it gets tangled in the apple tree.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to kite in tree, then back to presenter and book

[ETQ, p. 28] “How will he reach the kite?”

*(look at camera during ETQ, look & **point** to kite in tree, look at camera)*

[Book, p. 29] The tree will remind him of apple juice, so he’ll probably ask you for some

(turn page)

[Book, p. 30] And chances are,

[Book, p. 31] if he asks for some apple juice, (*turn page)*

[Book, p. 32] he’ll want a donut to go with it.

Camera focuses solely on presenter during ETQ below with background objects in view

[ETQ, p. 32] “Do you like donuts?” *(look at camera during ETQ, wait)*

[ETC] “I do!”

[End] “And that’s the end of the story”

***If you give a mouse a brownie* Script**

(Presenter holds book next to face with front of book towards camera)

[Introduction] "This book is called *If you give a mouse a brownie*. Written by Laura Numeroff and illustrated by Felicia Bond". *(look at camera during Intro, turn 3 pages)*

[Book, p.5] If you give a mouse a brownie, *(turn page)*

[Book, p.6] he's going to ask for some ice cream to go with it.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to brownie, then back to presenter and book

[ETC, p. 6] "What a big piece!"

(look at camera during ETC, look & ***point*** *to brownie, look to camera)*

[Book, p.7] When you give him the ice cream, *(turn page)*

[Book, p.8] he'll ask you for a spoon.

[Book, p.9] He'll start drumming on the table. Drumming will get him so excited he'll want to start a band.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to spoons, then back to presenter and book

[ETQ, p. 9] "Are the spoons his drum sticks?"

(look at camera during ETQ, look & ***point*** *to spoons, look to camera, turn page)*

[Book, p.10] You'll have to play guitar. He'll want to put on a show,

[Book, p.11] so you'll have to build a stage. Then you'll need some spotlights and a microphone. *(turn page)*

[Book, p. 12] When the stage is finished, [Book, p.13] *(turn page)*

[Book, p. 14] he'll want to make lots of tickets.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to tickets, then back to presenter and book

[ETQ, p. 14] "Who are the tickets for?"

*(look at camera during ETQ, look & **point** to tickets on lower left side of book, look to camera)*

[Book, p. 14 cont'd] You'll have to find paper and markers.

[Book, p. 15] When the tickets are done, he'll decide to make posters as well.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to mouse, then back to presenter and book

[ETC, p. 15] "He's having lots of fun"

*(look at camera during ETQ, look & **point** to mouse, look to camera, turn page)*

[Book, p. 16] He'll hang them all over the neighborhood.

[Book, p. 18] When he's out hanging them, it might start to rain.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to mouse, then back to presenter and book

[ETQ, p. 18] "Is he dancing in the rain?"

*(look to camera during ETC, look & **point** to mouse, look to camera)*

[Book, p. 19] He'll fold some posters and make a little boat. *(turn page)*

[Book, p. 20] Then he'll sail it in a puddle.

[Book, p. 21] *(turn page)*

[Book, p. 22] He'll get so wet he'll start to sneeze.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to bottom mouse's sneeze, then back to presenter and book

[ETC, p. 22] "He's making an achoooo!"

(look to camera during ETQ, look & ***point*** *to bottom mouse making an achoo, look to camera)*

[Book, p. 23] You'll have to put him in your pocket to stay nice and warm. When he peeks out of your pocket, he'll smell something delicious. The smell will remind him that he's hungry.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to aroma, then back to presenter and book

[ETQ, p. 23] "What can he smell?"

(look at camera during ETQ, look & ***point*** *to aroma, look to camera, turn page)*

[Book, p. 24] You'll have to take him to the store and get a few things to nibble on. Of course, he'll want to have a picnic.

Camera focuses solely on presenter during ETQ below with background objects in view

[ETQ, p. 24] "Have you ever had a picnic?"

(look at camera during ETQ, wait)

[Book, p. 25] When the sun comes out, you'll have to take him to the park. While you're setting up the picnic, he'll see a playground. He'll jump on the swings.

[Book, p. 26] He'll go as high as he can. When he looks up at the sky, he might notice a big white cloud.

[Book, p. 28] The cloud will remind him of ice cream.

[Book, p. 29] He'll probably ask you for some.

Camera focuses on presenter and book during ETQ, then zooms in on both pages during gestural point to sandpit, then back to book and presenter as presenter turns page

[ETC, p. 29] "He's diving into the sandpit"

(look at camera during ETC, look & ***point*** *to sandpit, look back at camera, turn page)*

[Book, p. 30] And chances are,

[Book, p. 31] if you give him some ice cream, *(turn page)*

[Book, p. 32] he'll want a brownie to go with it.

Camera focuses solely on presenter during ETQ below with background objects in view

[ETQ, p. 32] "Do you like brownies?" *(look to camera during ETQ, wait)*

[ETC] "I do!"

[End] "And that's the end of the story"

***If you give a pig a pancake* Script**

(Presenter holds book next to face with front of book towards camera)

[Introduction] "This book is called *If you give a pig a pancake*. Written by Laura Numeroff and illustrated by Felicia Bond". *(look at camera during Intro, turn 3 pages)*

[Book, p. 5] If you give a pig a pancake, *(turn page)*

[Book, p.6] she'll want some syrup to go with it.

Camera focuses on presenter and book during ETC below, then zooms in on both pages of book during gestural point on heat, then back to presenter and book

[ETC, p. 6] "That pancake looks warm"

*(look at camera during ETC, look & **point** to heat from pancake, look to camera)*

[Book, p.7] You'll give her some of your favorite maple syrup. *(turn page)*

[Book, p. 8] She'll probably get all sticky,

[Book, p.9] so she'll want to take a bath.

Camera focuses briefly on presenter during ETC below, then zooms in on both pages of book during gestural point to pig running upstairs, then back to presenter and book

[ETC, p. 9] "She's running up the stairs!"

*(look at camera during ETC, look & **point** to pig running upstairs, look back at camera, turn page)*

[Book, p. 10] She'll ask you for some bubbles.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages of book during gestural point to pig over bath, then back to presenter and book

[ETQ, p.10] "Is she diving into the bath?"

*(look at camera during ETQ, look & **point** to illustration of pig diving into bath, look back at camera)*

[Book, p. 11] When you give her the bubbles, she'll probably ask you for a toy. You'll have to find your rubber duck.

Camera focuses solely on presenter during ETQ below with background objects in view, then back to book and presenter as presenter turns page

[ETQ, p.11] "Do you like bubble baths?" *(look at camera during ETQ, wait, turn page)*

[Book, p. 12] The duck will remind her of the farm where she was born. She might feel homesick and want to visit her family.

Camera focuses on presenter and book during ETC below, then zooms in on both pages of book during gestural point to pig looking sad, then back to presenter and book

[ETC, p.12] "She looks sad"

*(look at camera with sad face during ETQ, look & **point** to sad pig, look back to camera)*

[Book, p. 13] She'll want you to come too. She'll look through your closet for a suitcase.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to clothes thrown out of cupboard, then back to presenter and book

[ETQ, p.13] " Can you see the suitcase?"

*(look at camera during ETQ, look & **point** to clothes thrown out of cupboard, back to camera, turn page)*

[Book, p. 14] Then she'll look under your bed. When she's under the bed, she'll find your old tap shoes.

[Book, p. 15] She'll try them on. She'll probably need something special to wear with them.

(turn page)

[Book, p. 16] When she's all dressed, she'll ask for some music.

[Book p. 17] You'll play your very best piano piece, and she'll start dancing.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to pig dancing, then back to presenter and book

[ETQ, p.17] "Is she happy dancing?"

(look at camera during ETQ, look & ***point*** *to pig dancing, look back at camera, turn page)*

[Book, p. 18] Then she'll want you to take her picture.

[Book, p. 19] So you'll have to get your camera. *(turn page)*

[Book, p. 20] When she sees the picture,

[Book, p. 21] she'll ask you to take more. Then she'll want to send one to each of her friends.

Camera focuses on presenter and book during ETC below, then zooms in on both pages during gestural point to pictures, then back to presenter and book

[ETC, p. 21] "Look at all the pictures!"

(look at camera during ETC, look & ***point*** *to pictures, look back at camera, turn page)*

[Book, p. 22] You'll have to give her some envelopes and stamps…

[Book, p. 23] and take her to the mailbox. On the way, she'll see the tree in your backyard. She'll want to build a tree house. *(turn page)*

[Book, p. 24] So you'll have to get her some wood, a hammer, and some nails.

[Book, p. 25] When the tree house is finished, *(turn page)*

[Book, p. 26] she'll want to decorate it.

Camera focuses on presenter and book during ETQ below, then zooms in on both pages during gestural point to tree house, then back to presenter and book

[ETQ, p. 26] "Is that tree house big?"

*(look at camera during ETQ, look & **point** to tree house, look back at camera)*

[Book, p. 27] She'll ask for wallpaper and glue. *(turn page)*

[Book, p. 28] When she hangs the wallpaper, she'll get all sticky. Feeling sticky will remind her of your favorite maple syrup.

[Book, p. 29] She'll probably ask you for some. *(turn page)*

[Book, p. 30] And chances are,

[Book, p. 31] if she asks you for some syrup, *(turn page)*

[Book, p. 32] she'll want a pancake to go with it.

Camera focuses solely on presenter during ETQ below with background objects in view

[ETQ, p. 32] "Do you like pancakes?" *(look at camera during ETQ, wait)*

[ETC] "I do!"

[End] "And that's the end of the story"

Key:

ETC – Extra-textual Comment

ETQ – Extra-textual Question

Extra-textual means that these are scripted words not in the book (i.e., they are 'extra' to the text of the book)

(Italicized text in brackets) – instructions for presenter

Highlighted Italicized text (above Extra- textual comments/questions) – instructions for cameraman