Novel Research Paradigms to Investigate Social Development in Typically Developing Infants and Infants at Elevated Risk for Autism Spectrum Disorder

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Abstract

A large body of research has examined social developmental processes in typically developing infants in the first year of life, and more recently in infants at higher familial risk for autism spectrum disorder (infant siblings) in order to uncover early behavioural markers for the disorder, essential for early diagnosis. The social stimuli presented in earlier research were often not representative of social experiences in the real world. For studies focussing exclusively on typical development, the use of inadequate stimuli means that the extent to which they produce findings that generalize to 'real world' social interactions is unclear. For the line of research involving infant siblings, these methodological issues have resulted in an ambiguous pattern of results. To address these issues, this thesis presents novel research methods that more closely approximate the interactive context in which social interaction typically occurs. This was achieved by developing a novel face scanning method - the gaze-contingency eye-tracking paradigm - in which infants could 'interact' with on-screen faces by fixating certain pre-specified regions of the face, providing a more realistic and socially demanding experience. Norms for typical behaviour within this paradigm were established (Chapter 3) and contrasted with behaviour from a sample of infant siblings (Chapter 3 & 4). The findings indicate that infant siblings show reduced social responsiveness relative to typically developing infants in this paradigm. These results were corroborated in an infant-parent free play task (Chapter 5), validating the efficacy of the gaze-contingency paradigm. Finally, infants' ability to follow human conversations as an observer was tested with novel cartoon stimuli providing evidence of early social understanding in typical development (Chapter 6). The novel methods are reviewed in terms of their added value to the field and findings are discussed in relation to their implications for typical and atypical development.

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Declaration

I declare that this thesis is my own work carried out under the normal terms of supervision.

Jolie R. Keemink

Publications

Within this thesis, Chapter 3 and 4 have been published, and Chapter 5 is under review for publication.

Chapter 3

Keemink, J. R., Keshavarzi-Pour, M. J., & Kelly, D. J. (2019). Infants' Responses to Interactive Gaze-Contingent Faces in a Novel and Naturalistic Eye-Tracking Paradigm. *Developmental Psychology, 55,* 1362-1371. doi: 10.1037/dev0000736

Chapter 4

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Chapter 5

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Chapter 1

Face Processing and Early Social Interaction in Typical Development during the First Year of Life

Ever since I was little, I have been fascinated by the notion that an infant grows into a toddler, a teenager and eventually into an adult. Compared to other animal species we actually develop remarkably slowly and are dependent on our caregivers for a relatively long period of time (Montagu, 1961). And yet, it seems unfathomable that we acquire so many skills at such a fast pace. Within the first year, we learn the essentials of walking, talking and communicating. However, these first, foundational steps of development do not always stick to their typical course with consequences for not only the developing child, but for entire families. As a researcher, I feel passionate about contributing to the knowledge on typical development, and to how we can recognise and offer support when children develop atypically. This thesis on social development in the first year of life was inspired by that passion and I feel grateful for the opportunity to contribute to the literature on early development. In this doctoral thesis I have endeavoured to advance the field of early typical and atypical social development in the first year of life, in the area of face scanning, parent-infant interaction and early social understanding. This first chapter will discuss the social milestones a typically developing infant reaches in the first year of life.

1.1. Interest in Faces from Birth

Although face processing is not the primary focus of this thesis, a brief description of what is known about newborn face processing supports the understanding of the following literature and the wider theoretical framework this thesis is based on. Therefore, I will start with a concise overview of the literature on early face processing.

From the earliest moments of life, human infants display social behaviour, one of the first indices being their demonstrable attraction to faces and face-like stimuli and their active search for mutual eye gaze (Farroni, Csibra, Simion, & Johnson, 2002; Johnson, Dziurawiec, Ellis & Morton, 1991; Mondloch et al., 1999; Valenza, Simion, Macchi Cassia & Umiltà, 1996). Moreover, some evidence even suggests that prenatal infants in the third trimester already preferentially orient towards a face-like configuration (Reid et al., 2017). Newborn infants recognise and prefer looking at their mother's face (Bushnell, 2001; Bushnell, Sai & Mullin, 1989; Pascalis, De Schonen, Morton, Deruelle & Fabre-Grenet, 1995), are sensitive to eye contact (Batki, Baron-Cohen, Wheelwright, Connellan & Ahluwalia, 2000; Farroni et al., 2002), as well as favouring attractive faces (Slater et al., 1998) and upright over inverted faces (Slater, Quinn, Hayes & Brown, 2001), further underlining the immediate and inborn relevance of faces. By 3 months of age, infants demonstrate recognition of individual faces (de Haan et al., 2001) and rapidly detect faces in natural scenes (Kelly, Duarte, Meary, Bindemann & Pascalis, 2019). Studies presenting infants with more complex, dynamic social scenes suggest that between 3 and 30 months old, infants increasingly direct their attention to the parts of a scene that are most socially relevant (Frank, Vul & Saxe, 2012).

1.1.1. The Importance of Faces

Evidence suggests that faces might well represent an innately meaningful stimulus category that provides us with an important source of social information, such as someone's age, gender, identity, attention, intentions, and emotions (Ellis & Young, 1998). In fact, research confirms that early visual attention and social engagement are associated with later social development. For instance, visual attention at 1 month of age and social orienting at 4 months of age are predictive of social attention behaviours at 18 months (Salley et al., 2016). Attention for their mother's eyes at 6 months of age is positively related to infants' social skills at 18 months (Wagner, Luyster, Yim, Tager-Flusberg & Nelson, 2013). Pons, Bosch & Lewkowicz (2019) presented a positive relationship between attention to the eyes of a talking face and social skills in infants aged 12 months. Similarly, research in the area of atypical social development shows that eye contact and attention to faces during dyadic interaction in the first year of life is associated with later social responsiveness in children with autism spectrum disorder (Clifford & Dissanayake, 2009). Collectively, these studies confirm that face scanning is a foundational skill for higher-order social behaviour. Arguably, during the preverbal stage of development, faces are of particular importance for social interaction, as infants are not yet able to rely on language to communicate.

Several neurological studies corroborate behavioural findings of the relevance of faces in early infancy and provide insights into the underlying neural substrates sub-serving early face processing. Electrophysiological studies with six-month-old infants demonstrate that objects and faces activate dissociable brain regions and show that unfamiliar faces and familiar faces produce differential responses as measured by event-related potentials (ERPs; De Haan & Nelson, 1997; De Haan & Nelson, 1999). Furthermore, infants show enhanced processing of faces with direct gaze by four months of age (Farroni et al., 2002). Additionally, localization methods allowed researchers to identify ERP components N290 and P400 in infants as young as three months as precursors to the component N170, which is thought to be a marker of specialized face processing in adults (Halit, De Haan & Johnson, 2003; Peykarjou & Hoehl, 2013). However, only at 12 months did these components reflect the specificity typically observed in N170 (Halit et al., 2003).

1.1.2. Development of Face Scanning Strategies

Over the course of the first year, infants' face scanning strategies become more pronounced. Between 3 and 11 weeks of age, a rapid increase in attention to faces takes place (Haith, Bergman & Moore, 1977) and at 6 weeks a clear preference for the eye region has been established (Hunnius & Geuze, 2004) that remains present until infants are approximately six months old (Di Giorgio, Méary, Pascalis & Simion, 2013; Haith et al., 1977; Oakes & Ellis, 2013; Maurer & Salapatek, 1976). Subsequently, infants start to shift their attention from the eye region to the mouth region of the face, which has been attributed to language learning (Lewkowicz & Hansen-Tift, 2011; Tenenbaum, Shah, Sobel, Malle & Morgan, 2013; Wagner et al., 2013). In addition to a change in attentional scanning strategies, the frequency and length of infants' fixations also changes with maturation. Over the first four months, the number of fixations significantly increases, whereas the fixations length steadily declines (Hunnius & Geuze, 2004). Furthermore, infants' initial attention and scanning patterns are primarily informed by saliency and a preference for top-heavy stimuli (Macchi, Turati & Simion, 2004; Turati, Simion, Milani & Umilta, 2002), but over time become increasingly characterised by intentionality and volition (Bronson, 1994; Kato & Konishi, 2012). Infants establish a stable and adult-like viewing pattern at approximately four months of age (Bronson, 1994; Hunnius & Geuze, 2004).

1.1.3. Early Experience and Face Scanning

Several researchers have repeatedly stressed the importance of early visual experience for the development of face processing expertise (Johnson & Morton, 1991; Halit et al., 2003; Nelson, 2001; Schonen & Mathivet, 1989; Simion & Di Giorgio, 2015) and numerous empirical studies support this account. As infants gain more experience in the social world, their visual preferences and recognition abilities are shaped accordingly, a process referred to as perceptual narrowing. For instance, when infants are born, they do not show a spontaneous preference for faces corresponding with their own race, but at 3 months, infants demonstrate a strong preference for faces belonging to their own ethnic group (Bar-Haim, Ziy, Lamy & Hodes, 2006; Kelly et al., 2005; Kelly et al., 2007a). Furthermore, by 9 months of age ‘the other-race effect’ emerges meaning infants are only able to discriminate between faces from their own race group but not others, as measured by the Visual Paired-Comparison task (Kelly et al., 2007b). There is also some evidence suggesting that 6- and 9-month-old infants demonstrate different scanning strategies for own- and other-race faces (Xiao, Xiao, Quinn, Anzures & Lee, 2013). In addition to becoming an expert in discriminating amongst faces in one’s own ethnic group, research has shown that over the course of the first year, infants develop a species-related expertise. Six-month-old infants are still able to discriminate amongst both monkey and human faces, but at the end of the first year of life are no longer able to do so for monkey faces (Fair, Flom, Jones & Martin, 2012; Pascalis, De Haan & Nelson, 2002), an effect that has been replicated for non-primate animal faces (Simpson, Varga, Frick & Fragaszy, 2010). Interestingly, this perceptual narrowing has be shown to be plastic and seems reversible in 6-10-month-old infants after increased exposure to other-race faces (Anzures et al., 2012) and other-species faces (Pascalis et al., 2005). Similar findings have been reported for gender. Three-month old infants primarily raised by a female caregiver display a preference for female faces, whereas infants cared for by a male caregiver prefer looking at male faces (Quinn, Yahr, Kuhn, Slater & Pascalis, 2002). Additionally, there is some evidence suggesting that newborn infants preferentially look at faces with a happy expression over neutral and fearful expressions as a result of being exposed to this expression in the first few days of life (Farroni, Menon, Rigato & Johnson, 2007). The importance of early experience is further demonstrated by evidence from studies with older participants who were deprived of patterned visual input during the first few weeks after birth due to bilateral congenital cataracts. These participants show consistent difficulties with face recognition compared to age-matched controls when the orientation or facial expression of a face changed (Geldart, Mondloch, Maurer, De Schonen & Brent, 2002; Le Grand, Mondloch, Maurer & Brent, 2003). Collectively, these studies highlight the impact of early experience on later face processing abilities.

1.1.4. Theoretical Accounts

Although researchers seem to agree on the putative early importance of faces, the necessity of early experience has been disputed. Researchers have attempted to explain the reported early face preference and rapidly maturing face processing system by proposing developmental accounts of its origin. One prevailing theory proposes a dual process account of face processing (Morton & Johnson, 1991). Infants supposedly are born with a structure termed CONSPEC, an innate system that directs newborn infants' attention to *detect* faces and face-like patterns in order to gain experience with this stimulus group. At approximately two months of age, infants attain CONLERN, a system under specialised cortical control that supports infants' learning of the visual differences of conspecifics to facilitate face *processing* and *recognition*. Essentially, CONSPEC biases visual input in the first months of life and consequently lays the foundation for the more specialised and cortically located mechanism CONLERN. After two decades of novel empirical evidence, Johnson and colleagues extended this model by including the fast-track modulator model, which accounts for the finding that perceived eye contact modulates infants' neural and behavioural response to faces (Johnson, Senju & Tomalski, 2015; Senju & Johnson, 2009). Opponents of this view argue that the more specialised features of CONLERN are already present at birth as evidenced from the more robust preferences for attractive faces and faces engaging in eye contact (Quinn & Slater, 2001; Quinn & Slater, 2003; Farroni et al, 2002). The precise systems underlying the face preference at birth, and whether these are modular or general, remain subject to debate, and the reported face bias in early infancy continues to be controversial (Gauthier & Nelson, 2001; Leppänen, 2016; Pascalis & Kelly, 2009; Simion & Di Giorgio, 2015)

1.2. Expressive Faces

The literature discussed up to this point predominantly examined infants' eye-movements to faces without consideration of a particular facial expression. The faces that infants encounter in day to day life do however display variations to the neutral physiognomy presented in these studies; expressions that convey essential socio-communicative signals. As understanding about emotions and recognition of emotional expressions is pivotal for social survival, infants need to rapidly develop the ability to discriminate, categorize and comprehend an abundance of different expressions (Izard et al., 2001). Numerous studies have investigated the development of expression perception, predominantly focussing on the six basic expressions (happiness, anger, surprise, fear, disgust and sadness; Ekman, 1973).

1.2.1. Expression Discrimination

As discussed earlier, presumably shaped by the earliest experiences, newborn infants as young as two days old primarily look at happy faces (Farroni et al., 2007), and there is some evidence suggesting that newborns can discriminate between happy, sad, and disgusted faces (Addabo, Longhi, Marchis, Tagliabue & Turati, 2018; Field, Woodson, Greenberg & Cohen, 1982). From three months old, infants show discrimination of happy expressions from surprised and frowning faces (Young-Browne, Rosenfeld & Horowitz, 1977; Barrera & Maurer, 1981), whereas happy-angry and happy-fearful discrimination develop around 4- and 7-months of age respectively (LaBarbera, Izard, Vietze & Parisi, 1976; Nelson & Dolgin, 1985). Discrimination amongst sadness, anger and surprise combinations seems to arise at 5 months (Schwartz, Izard & Ansul, 1985), but the order of presentation seems consequential, as well as the infant's emotional environment (De Haan, Belsky, Reid, Volein & Johnson, 2004). In addition to findings from behavioural studies using looking paradigms, neurological research as well as research collecting pupillary responses confirms evidence of expression discrimination in early infancy (Jessen, Altvater-Mackensen & Grossman, 2016; Leppänen, Kauppinen, Peltola & Hietnanen, 2007; Xie, McCormick, Westerlund, Bowman & Nelson, 2018). Together these findings demonstrate that infants learn to discriminate between basic emotional expressions in the first year of life.

1.2.2. Expression Categorisation

After expression *discrimination* has been established, infants need to learn the skill of expression *categorisation*, evidenced by a similar response to expressive faces that are perceptually different, but belong to the same category (e.g. open vs. closed smiles). Evidence for categorisation of happy and fearful expressions is found in 4- to 7-month-old infants (Bornstein & Arterberry, 2003; Cong et al., 2018; Caron, Caron & MacLean, 1988; Ludemann & Nelson 1988), as well as categorisation of fear and anger (Serrano, Iglesias & Loeches, 1992), and happiness and surprise (White et al., 2019). However, findings are mixed with many studies reporting no evidence of categorisation and results seem dependent on the order of stimulus presentation (e.g. Kotsoni, De Haan & Johnson, 2001; Nelson & Dolgin, 1985; Phillips, Wagner, Fells & Lynch, 1990; Serrano, Iglesias & Loeches, 1995). The conceptual, broader categorisation of positive and negative emotions does not seem to occur until infants are ten months old (Ludemann, 1991).

1.2.3. Expression-specific Eye Movements

In addition to the examining development of discrimination and categorisation using preferential looking paradigms, researchers have probed the visual scanning paths for different expressions to examine if infants show expression-specific eye movements. Hunnius, De Wit, Vrins and Von Hofsten (2011) report that 4- and 7-month-old infants' exhibit more avoidant looking patterns toward threat-related emotions (fear, anger), potentially indicating a certain vigilance. By contrast, Miguel, McCormick, Westerlund and Nelson (2019) found longer looking times towards fearful compared to angry and happy faces. Interestingly, Geangu et al. (2016) reports cultural differences in scanning patterns of happy and fearful faces. In the second year of life, infants show expression-specific eye movements for happy, neutral and fearful faces (Gredebäck, Eriksson, Schmitow, Laeng & Stenberg, 2011). These findings tentatively suggest that infants employ expression-specific eye movements, but further research with larger developmental samples including all six universal expressions as stimuli is needed to understand the precise nature of expression-specific scanning pathways.

1.2.4. Expression Comprehension

Discrimination and categorisation provide evidence that infants can perceive the *perceptual* difference between expressions. However, the mastery of these skills does not provide information about infants' ability to comprehend the *conceptual* differences between expressions. Arguably, discrimination and categorisation can follow from the ability to decode lower-level visual properties, whereas emotion comprehension, understanding the social meaning that the different expressions convey, relies on higher-order processes. Only a handful of studies have explicitly addressed the development of emotion comprehension in the first year of life. One study concluded 7-month-olds show some understanding of the meaning of expressions, using a method called 'metaphorical mapping' in which 7-month-old infants had to correctly match auditory tones (happy/sad) to corresponding facial expressions (Phillips et al., 1990). A more recent study by Soussignan et al. (2017) report 7- and 12-month-olds demonstrate valence-congruent responses towards dynamic expressive faces and infer basic understanding of expression valence. Several studies conclude an attentional bias towards fearful faces, supposedly serving an adaptive function (Vaish, Grossmann & Woodward, 2008), although evidence is mixed (Heck, Hock, White, Jubran & Bhatt, 2016; Leppänen & Nelson, 2012; Peltola, Hietanen, Forssman & Leppänen, 2013). Other studies reason that infants are capable of understanding the valence of emotions, but evidence is either theoretical (Tronick, 1989) or limited to mothers' faces (Sorce, Emde, Campos & Klinnert, 1985; Sroufe, 1979). A study including older infants (14-18-month-olds) find some evidence for infants having conceptual categories for different negative emotions (Ruba, Meltzoff & Repacholi, 2019), however not all results replicated. Emotion comprehension seems to follow a more protracted course, but further study is needed to unravel the details of its development.

1.3. Dyadic Interaction

The presented evidence demonstrates how in the first months of life infants rapidly acquire the face processing skills foundational for later social development. Following from these foundations, infants become increasingly initiated in the rituals of human social interaction. Visual attention towards faces plays an essential role in initiating interaction and forms the principle of turn-taking behaviour (Hessels, 2020). Human conversations follow a sequential structure, and from very early on infants start to build the foundations for these structures with input from their caregiver.

Furthermore, infants appear to be sensitive to violations of typical interaction structures from the first few months of life. This section will discuss studies that have examined the earliest forms of dyadic behaviour, and specifically the social behaviours relevant to the experimental chapters in this thesis (Chapter 3-6).

1.3.1. Reciprocity and Social Contingency

Two essential elements of human social interaction are reciprocity and contingency. Reciprocity pertains to the turn-taking behaviour inherent to human social interaction. Through reciprocal behaviour, humans construct a positive and mutual exchange. Contingency refers to the notion that our social responses are dependent on each other. A response within an interaction is typically not random but depends on the most recent behaviour or utterance from the interaction partner. These two behaviours, reciprocity and contingency, are foundational building blocks for the structure and rhythm of human interactions (Leonardi, Nomikou, Rohlfing & Raczaszek-Leonardi, 2016).

Research suggests that adults rely heavily on lexical information to guide their turn-taking behaviour within interaction (De Ruiter, Mitterer & Enfield, 2006). Nevertheless, infants already start to show reciprocal and contingent behaviours, as well as displaying sensitivity to the presence and absence of these behaviours in an interaction well before they develop language. Several studies suggest that 1- to 2-month-old infants engage in proto-conversations, which are conversation-like interactions involving reciprocal behaviours (Braten, 1988; Caskey, Stephens, Tucker & Vohr, 2011; Gratier et al., 2015; Kokkinaki, 2010). Three-month-old infants engage in relatively stable and timely turn-taking patterns during interaction with their parent

(Hilbrink, Gattis & Levinson, 2015). From, 4 months of age, infants start to show more positive affect when an adult follows the timing and structure of a peekaboo game relative to when the usual structure has been abandoned (Rochat, Querido & Striano, 1999). Regarding contingency, research suggests that 2-month-old infants display expressive changes in response to non-contingent interactions relative to contingent interactions (Soussignan, Nadel, Canet & Gerardin, 2006). Furthermore, 2-month-old infants appear to calibrate their levels of social contingency to maternal patterns of contingent responsiveness (Bigelow & Rochat, 2006). Similarly, responsive mothers are attuned to their infants' contingencies suggesting mutual regulation (Van Egeren, Barratt & Roach, 2001).

A frequently used research paradigm to examine infants' development of and sensitivity to reciprocity and social contingency in the first year of life is the Still Face Paradigm (Tronick, Als, Adamson, Wise & Brazelton, 1978). In this paradigm, a caregiver is asked to engage with their infant in a typical manner. During normal social interaction with their caregiver, infants smile frequently and engage in eye contact. After a few minutes of normal engagement, the caregiver is told to withdraw from the interaction with their infant and is asked to maintain a neutral and unresponsive expression. Infants typically respond to this sudden withdrawal with increased arousal and they appear to make efforts to re-engage their caregiver, but eventually, they disengage. When the caregiver is prompted to re-engage with their infant, infants respond with initial wariness, but quickly come around and return to positive, interactive behaviour. Infants as young as one month old are capable of detecting a violation in typical interaction with their caregiver during the Still Face Paradigm. With this paradigm, Tronick et al. (1978) highlight the importance of parental reciprocity and contingent responsiveness, as well as infants' early sensitivity to these processes. The significance of infants' response to an unusual violation of the 'reciprocal contract' is illustrated by studies demonstrating that infants are less perturbed by other disruptions such as a caregiver disengaging to speak to someone else (Murray & Trevarthen, 1985) or a brief physical separation (Field, Vega-Lahr, Scafidi & Goldstein, 1986). Furthermore, infants' responses to the Still Face Paradigm have been linked to attachment style (Cohn, Campbell & Ross, 1991) and behavioural issues in toddlerhood (Moore, Cohn & Campbell, 2001). The robust effect of the Still Face Paradigm has been replicated and extended comprehensively (see reviews Adamson & Frick, 2003; Mesman, Van Ijzendoorn & Bakermans-Kranenburg, 2009).

1.3.2. Imitation

Another early dyadic skill observed in infancy is imitation. Imitation is commonly viewed as an important social behaviour promoting infants' developing understanding of other persons. It is proposed that early imitation allows infants to form a connection to social partners and create the feeling that others are 'like me' (Meltzoff, 2005). Imitation has also been suggested as a precursor to later empathy (Meltzoff, 2002; Meltzoff, 2005). Nagy (2006) suggest that early imitation serves as a prototype of dialogue without using language. Controversially, there are studies suggesting that infants already display imitation of facial actions in the first few days of life, as well as copying manual and head movements (Field et al., 1982; Meltzoff & Moore, 1977; Meltzoff & Moore, 1983; Meltzoff & Moore, 1989; Vinter, 1986). Some researchers propose this as evidence of an 'innate mimicry system' (Chartrand & Van Baaren, 2009; Nagy, 2006; Meltzoff & Moore, 1989). However, this notion is strongly questioned, and the evidence for neonatal imitation has been heavily disputed

(Kaitz, Meschulach-Sarfaty, Auerbach & Eidelman, 1988; Oostenbroek, Slaughter, Nielsen & Suddendorf, 2013). Various studies present findings concluding that neonatal imitation is limited to the action of tongue protrusion (Anisfeld et al., 2001; Heimann, Nelson & Schaller, 1989; Jones, 1996), or not present at all (Hayes & Watson, 1981; Koepke, Hamm, Legerstee & Russell, 1983; McKenzie & Over, 1983). These mixed findings have been attributed to methodological differences, and Oostenbroek et al. (2013) argue for more naturalistic observation methods to resolve this debate.

More recent evidence suggests that the robust imitation of facial actions does not emerge until four months of age (De Klerk, Hamilton & Southgate, 2018; Isomura & Nakano, 2016). Similarly, infants start to imitate the pitch and frequency of vocal sounds around the same time (Kokkinaki & Kugiumutzakis, 2000; Maratos, 1973; Trevarthen, 1979). Consistent imitation of manual dexterities, such as handclapping, waving and tapping occurs slightly later (Jones, 2007), and Jones (2009) concludes that infants do not reliably and consistently imitate actions until the second year of life. Aligning with their results on emotion comprehension, Soussignan et al. (2017) probed early mimicry of facial expressions (joy, anger, fear, disgust, and sadness) using Baby-FACS, a precise method for coding facial expressions examining micro-movements in the infant’s face. The authors found no evidence of full facial imitation of expressions in 3 to 12-month-old infants. Infants’ facial movements only seem to reflect the valence (positive/negative) of the viewed expression. More research is required to investigate the developing ability of the imitation of emotional expressions.

1.3.3. Social Smiling

One expression that is of significant importance within human social interaction and cooperation is the happy expression, or smile (Dunbar & Mehu, 2008). It is an everyday non-verbal communicative signal that appears to be socially motivated (Kraut & Johnston, 1979). Human infants display spontaneous smiles from birth, which are called endogenous smiles. Neonatal smiles are typically not yet attributed to external, social stimulation and often occur during active sleep (Messinger & Fogel, 2007; Spitz, Emde & Metcalf, 1970; Sroufe & Waters, 1976). However, there is some research suggesting that newborns already demonstrate smiling in response to social interaction (Cecchini, Baroni, Di Vito & Lai, 2011). The type of smile that reflects enjoyment and is commonly viewed as socially meaningful is classified as the 'Duchenne smile', characterised by activation of the muscles around the eyes and cheeks, and the lifting of the mouth corners (Ekman, Davidson, Friesen & Wallace, 1990; Messinger & Fogel, 2007). Research suggests that it is not until the age of 6 weeks that infants' smiles are reliably associated with social interaction (Anisfield, 1982). From this age, infants' smiles become more voluntary (Malatesta et al., 1989). Initially, social smiling happens in response tactile and auditory stimulation (e.g. tickling and talking) and over the course of the first year, visual social events also start to elicit social smiles (Sroufe & Waters, 1976). During interaction with their infant, mothers typically smile at their infant, both in absence and presence of an infant smile (Cohn & Tronick, 1987). Contrastingly, infants are more likely to smile only when their mother is already smiling at them (Messinger, Fogel & Dickson, 2001). The development of laughter, the superlative of smiling, has been documented at approximately 4 months of age and usually requires more intense social stimulation relative to smiling (Sroufe & Waters, 1976; Sroufe & Wunsch, 1972). With the development of social smiling and reliable facial imitation, infants show the first intentional, unambiguous signs of mutual social engagement. This marks an important point in their social development, as parents notice the increased reciprocity, which serves as positive feedback. As a result, parents start to fine-tune the communication with their infant and engage in more structured playful interaction (Fogel, 1993; Rochat et al., 1999).

Later in the first year of life, at approximately eight months of age, a novel type of social smiling is observed that has been described as anticipatory smiling (Jones & Hong, 2001; Parlade et al., 2009; Venezia, Messinger, Thorp & Mundy, 2004). This form of smiling occurs when an infant is playing with an object, then smiles and subsequently turns their head to establish social contact with their parent, the smile thus anticipating the head turn. Anticipatory smiling increases between 8 and 12 months (Jones & Hong, 2001; Parlade et al., 2009) as infants become increasingly socially proficient. The production of anticipatory smiles has also been linked to measures of prosocial behaviour at 30 months (Parlade et al., 2009). An anticipatory smile serves as affect communication and an attentive, responsive parent appears to be essential for anticipatory smiling to occur (Jones & Hong, 2005), which highlights the communicative function of smiling.

The importance of the social context of smiling is illustrated further in a study by Jones, Collins and Hong (1991), who demonstrate an ‘audience effect’ in 10-month-old infants. This effect implies that infant smile production is significantly affected by the presence or absence of attentive spectators. Furthermore, a recent study examining the genetic and environmental contributions to the development of smiling suggests a significant impact of the early family environment (Planalp, Van Hulle, Lemery-Chalfant & Goldsmith, 2017). For healthy emotional development, infants need to experience frequent and consistent parental positive affect. Additionally, studies including developmental populations at risk for atypical social development (such as autism spectrum disorder and affective disorders) seem to indicate that these infants display fewer social smiles in comparison to typically developing peers (Field, Diego & Hernandez-Reif, 2009; Harker, Ibanez, Nguyen, Messinger & Stone, 2016), highlighting the importance of social smiling as part of typical development. Collectively, these studies show that from early on infant smiling serves an important communicative function within social interaction, and that young infants' smile production is affected by the social context.

1.4. Triadic Interaction

With maturation, the acquired skills and patterns to engage in dyadic interaction are followed by the development of the ability to engage in triadic interaction, also referred to as joint attention. Having mastered joint attention, an infant can coordinate their attention between an object of interest and an interaction partner who is simultaneously attending to the same object (Bakeman & Adamson, 1984). At approximately 8 to 10 months of age infants start to engage in joint attention behaviours (Corkum & Moore, 1998; Mundy et al., 2007), but before that infants already show important precursors to joint attention, such as gaze-following and mutual social engagement (D'Entremont, Hains & Muir, 1997; Salley et al., 2016). Mundy et al. (2007) distinguish between two types of joint attention behaviours: *responding* to joint attention, referring to the ability to respond to joint attention bids from an interaction partner by following gaze or gestures, and *initiating* joint attention, the ability to use eye contact to establish joint attention with an interaction partner.

Both types of joint attention behaviours increase with age and infants refine these skills in the second year of life (Mundy et al., 2007). The development of these joint attention behaviours also relates to anticipatory smiling, discussed in the previous section, during which infants communicate positive affect about an object to an interaction partner by coordinating their attention between the two (Venezia et al., 2004).

In their paper on cultural learning, Tomasello, Kruger and Ratner (1993) discuss the underlying social-cognitive mechanisms of joint attention and propose that joint attention abilities are sub-served by a maturing competence to view others as intentional and agentic beings. According to this view, the development of joint attention is enabled by the growing understanding that others selectively and meaningfully attend to certain aspects of their environment, and that this can serve as a communicative signal. This notion illustrates infants' earliest steps into the development of perspective taking (Tomasello et al., 1993). In fact, joint attention appears to be an important precursor for higher-order social-cognitive abilities, most specifically language (Brooks & Meltzoff, 2005; Markus, Mundy, Morales, Delgado & Yale, 2000; Mundy et al., 2007). Furthermore, not long after infants learn to engage in joint attention, they start showing signs of social referencing, a novel social skill that allows infants to reference a social partner's reaction or affective state in ambiguous situations (Source et al., 1985; Striano & Rochat, 2000). Together, these studies provide converging evidence that over the course of the first year of life infants social behaviour becomes increasingly complex, as they learn to integrate their acquired skills.

1.5. Conclusion and Next Steps

Collectively, the research discussed in this chapter demonstrates that from the earliest moments of life, human infants engage in social behaviour, evidenced by their attention to faces, subtle facial imitation, and early smiling. Over the course of their first year, infants' social behaviour becomes more refined and by the time of their first birthday, infants have demonstrably grown into agentic beings capable of purposeful communication and perceiving others as intentional beings (Carpenter, Nagell, Tomasello, Butterworth & Moore, 1998).

Although the literature agrees on the rapid emergence of novel social behaviour in the first year of life, the details on the development and origin of certain types of social behaviour remain subject to debate. This chapter mentioned the controversies around the early face bias, emotion comprehension and early imitation. For the progression of the field, it is essential that researchers scrutinize the methods they employ, so that research conclusions are reliable, replicable, and generalizable. This thesis aligns with this notion by introducing novel methods to study early socio-communicative behaviour and examining behaviour across different contexts in the upcoming experimental chapters (Chapter 3-6). Furthermore, by optimising our conclusions about typical development, clear norms for typical behaviour can be established, which will benefit the study of atypical behaviour. This first chapter focussed on typical social development in the first year of life, however, development does not always follow this typical pattern. The next introductory chapter will discuss the development of infants at heightened genetic risk for atypical development to provide insight into what happens when social development deviates from its typical course.

Chapter 2

Infant Siblings of Children with Autism Spectrum Disorder: The First Year of Life

2.1. Introduction

The first chapter of this thesis concluded that typically developing infants are naturally inclined to seek out social engagement and over the first year acquire an abundance of socio-communicative skills. However, human development does not always follow its typical course. A specific subgroup of infants at risk for atypical development are the infant siblings of children with Autism Spectrum Disorder (hereafter ASD), who are born with a higher genetic likelihood to develop ASD. Approximately 20% of infants with a diagnosed older sibling receive a diagnosis themselves at 36 months (Ozonoff et al., 2011b) relative to a 1% prevalence rate in the general population (Baird et al., 2006). Furthermore, a considerable proportion of non-diagnosed infant siblings present with other developmental concerns (Charman et al., 2017; Piven, Elison & Zylka, 2018). Over the past decade, researchers have started to study the early development of infant siblings, which has provided a promising opportunity for the prospective exploration of the emergence of ASD. This line of research aims to uncover early endophenotypic markers of ASD observable in the first few years of life. Not only will this lead to invaluable knowledge on the underpinnings of this pervasive and heterogeneous disorder, but - perhaps even more importantly – it will play a pivotal role for the development of early detection instruments and subsequent early treatments. In this thesis, I will aim to contribute to the literature on the development of infant siblings. This second introductory chapter will firstly outline the core symptoms of ASD, its development and genetic underpinnings, before giving a comprehensive overview of the literature on infant siblings. Subsequently, I will discuss how this thesis will attempt to fill a gap in this research area.

2.2. Autism Spectrum Disorder

Autism spectrum disorder is a pervasive neurodevelopmental disorder characterized by impairments in social interaction and communication, and repetitive behaviours and restrictive interests (American Psychiatric Association (APA), 2013). In this thesis, the focus will specifically lie on the early social and communicative manifestations of ASD. Although less extensively studied compared to the social and communicative symptoms of ASD, repetitive behaviour and restrictive interests are an important characteristic of ASD and comprise a broad range of different behaviours. I refer to Turner's (1999) review for a more thorough description of the repetitive behaviours commonly observed in ASD, as it is beyond the scope of this chapter.

At its core, ASD represents an impairment in typical social functioning, demonstrated by a lack of social and emotional reciprocity and difficulties with understanding non-verbal communication (APA, 2013). These social impairments are reflected in everyday experiences, as is shown for example by Orsmond, Krauss and Seltzer (2004) in their comprehensive study examining the presence and characteristics of peer friendships in individuals with ASD. The authors report that individuals with ASD have difficulties developing and maintaining in-depth friendships outside of pre-arranged settings. In addition, they are more likely to spend their free time engaging in activities that do not require social interaction.

Paradoxically, even though individuals with ASD actively seek out solo experiences, both children and adults with an ASD diagnosis report higher levels of loneliness than their neuro-typical counterparts and seem to have greater difficulties understanding these feelings (Bauminger & Kasari, 2000; Mazurek, 2013). In addition to experiencing difficulties with forming and maintaining friendship bonds, individuals with ASD struggle to develop romantic relationships (Howlin, Mawhood & Rutter, 2000).

In the most recent version of the Diagnostic and Statistical Manual of Mental Disorders (DSM-V, APA, 2013), the previously distinguished types of autism, such as Asperger's Syndrome and PDD-NOS, were combined under the new umbrella term autism spectrum disorder. Individuals diagnosed with ASD are now located somewhere on the spectrum and the severity and complexity of symptoms can therefore vary substantially between individuals with the same diagnosis. Consequently, ASD can be seen as a highly heterogeneous disorder, ranging from individuals who are high-functioning and attend university to individuals with severe intellectual disabilities who need constant care. Symptoms are similar in quality but vary significantly in quantity (Folstein & Rosen-Sheidley, 2001), which results in great challenges for detection, treatment and research on ASD.

2.3. ASD: A Developmental Disorder

The pervasive and developmental nature of ASD means it is manifested from childhood and is visible in numerous areas of development. I will discuss the most important behavioural manifestations in early development and explicate how they differ from typical development.

2.3.1. Joint Attention in ASD

As discussed in Chapter 1, typically developing infants perform joint attention behaviours when they are approximately nine months old (Mundy et al., 2007). Having mastered joint attention, an infant can switch its attention between an object of interest and an interaction partner who is simultaneously attending to the same object. Children with an ASD diagnosis still seem to have difficulties displaying this behaviour when they are two years of age (Mundy, Sigman & Kasari, 1990), which appears to be related to impairments in affect sharing (Kasari, Sigman, Mundy & Yirmiya, 1990). Charman (2003) argues that joint attention is of crucial importance within ASD as impairments in joint attention abilities are amongst the earliest symptoms. Furthermore, joint attention abilities are positively associated with both social and language outcomes in children with ASD (Charman, 2003), making it a promising target for intervention.

2.3.2. Language Development in ASD

Associated with joint attention impairments, language development in children with ASD is often significantly delayed compared to their peers. The overall pattern and variability in language acquisition appears to be comparable with typically developing peers, but word comprehension, word production and the use of gestures develop much later in children with ASD (Charman, Drew, Baird & Baird, 2003). Assessment of language development is an important part of the diagnostic process of ASD since delays in language production are often relatively easy to observe. Parents often report a lack of babbling and delayed first words as one of their first concerns when consulting a health visitor (Mitchell et al., 2006). Mitchell et al. (2006) also advocate for surveillance of gesture development, which may present as one of the earliest signs of ASD, noticeable before language should typically occur. Additionally, Charman and Baird (2008) propose a strong focus on early non-verbal behaviour in clinical assessments.

2.3.3. Theory of Mind in ASD

Another symptomatic manifestation of ASD that has been extensively discussed in the literature is a deficit in Theory of Mind (Baron-Cohen, Leslie & Frith, 1985; Happé, 1994). Premack and Woodruff (1978) explain Theory of Mind as the ability to attribute mental states, beliefs and feelings to the self and to other people. Specifically, having a Theory of Mind allows us to infer mental states and make predictions about other people's behaviour. This ability is commonly tested using two types of tasks. First-order tasks examine if an individual understands that other people can hold beliefs that are different to their own beliefs ("I understand that she thinks…"). Second-order tasks test the higher-order understanding that person A understands what person B thinks ("I understand that she knows that he thinks…"). Baron-Cohen et al. (1985) were the first authors to hypothesize that children with ASD do not develop a Theory of Mind to the extent that typically developing children do. Compared to typically developing peers, the children with ASD in their sample failed to attribute beliefs to others in a puppet play paradigm. The authors proposed this deficit as one of the core underlying components of the social impairments in ASD. Although this account has been challenged with results showing that some individuals do pass first-order Theory of Mind tasks (Frith & Happé, 1994; Happé, 1994; Ozonoff, Pennington & Rogers, 1991), severe impairments in second-order representations seem to be present in high-functioning children with ASD (Baron-Cohen, 1989), and even adults with ASD who do pass second-order Theory of Mind tasks fail to pass more naturalistic and complex story tasks (Happé, 1994).

2.3.4. Play Behaviour in ASD

Arguably, difficulties with the attribution of mental states to other beings also has consequences for the way children with ASD structure their play. Accordingly, children with ASD demonstrate differences in play behaviour compared to their typically developing peers (Baron-Cohen, 1987; Kanner, 1943; Koegel, Koegel, Frea & Fredeen, 2001; Wing, Gould, Yeates & Brierly. 1977). Typically developing children often engage in pretend play, in which the child plays with an object pretending it is something different than its real entity (e.g. pretending a hairbrush is a phone). In order to engage in this type of play, the child must have an understanding both of what the object is in reality, and what it represents during play (Baron-Cohen, 1987). In other words, the child must hold a second-order representation similar to the mental states described in Theory of Mind. Pretend play can be contrasted with functional play, in which play objects preserve their original function. Research into the play behaviour of children with ASD shows that compared to typically developing children they engage in less spontaneous pretend play (Baron-Cohen, 1987). Furthermore, play behaviour in children with ASD is predominantly characterized by parallel and solitary functional play (Holmes & Willoughby, 2009) and considerable difficulties with social play (Jordan, 2003).

2.3.5 Visual Attention to Faces in ASD

In the context of early social behaviour, Kanner (1943) first characterized the clinical image of the disorder then called autism by an early inattentiveness to faces and a lack of eye contact. Contrastingly, as became evident in the previous chapter, research with typically developing infants convincingly demonstrates a strong face preference and more specifically an eye preference (Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996), and these behaviours seem to be important precursors and prerequisites for further social development (e.g. Farroni et al., 2002). Supporting Kanner's (1943) original descriptions, clinical observations and parental interviews about their personal experiences with their child with ASD report diminished eye contact, lack of gaze following, no social smiling and no desire to interact (Volkmar, Chawarska & Klin, 2005). Furthermore, studies using data from early home videos delineate a substantial lack of orienting to and looking at other people (Baranek, 1999; Osterling & Dawson, 1994). Collectively, the findings from these studies concerning various areas of early development all converge to demonstrate that impairments in social cognition are ubiquitous among children with ASD and present very early in life.

2.4. Theoretical accounts of ASD

Several researchers have proposed theoretical accounts to explain the mechanisms underlying the core symptoms of ASD. These theories can be roughly divided into two categories: social and non-social theories. The most prominent social theories suggest the core deficit of ASD lies in a difficulty to understand others. They explain ASD as a function of a deficit in theory of mind (Baron-Cohen et al., 1985) supposedly resulting in an inability to impute beliefs to others, or as an extreme male brain (Baron-Cohen et al., 2002) causing individuals with ASD to be very developed in systemising, but not in empathising. Another social theory views a social motivation deficit as the central explanation for the reduced social orientation observed in ASD (Chevallier, Kohls, Troiani, Brodkin & Schultz, 2012). Conversely, the non-social theories propose autistic symptoms are caused by a general cognitive or perceptual deficit, such as executive dysfunction function (Hill, 2004) or weak central coherence (Happé, Frith & Briskman, 2001). A third, more contemporary non-social theory describing both the hyper- and hyposensitivity observed in individuals with ASD is the Bayesian explanation of ASD (Pellicano & Burr, 2012). Bayesian decision theory poses that perceptual experience is affected by both sensory input and prior knowledge about the world (Knill & Pouget, 2004). The Bayesian framework of ASD suggests that individuals with ASD are characterised by an attenuated ability to take into account prior knowledge, they experience so-called hypo-priors, resulting in a more accurate perception of the world and therefore a different interpretation of sensory input (Pellicano & Burr, 2012).

More recently, researchers have identified important limitations to the earlier proposed theoretical accounts of ASD (Van de Cruys, et al., 2014). Firstly, these theories often emphasize only one cluster of symptoms of ASD, either the difficulties with social interaction and communication, or the presence of restrictive and repetitive behaviours. Secondly, the core deficits they propose, a Theory of Mind deficit, executive dysfunction and weak central coherence, are not specific to ASD, nor are they present in every person with a diagnosis. Thirdly, the cognitive mechanisms underlying the suggested deficits are not clearly defined. As a response, a novel theoretical framework has been introduced that offers to address these limitations and attempts to account for the full range of behavioural symptoms characteristic of the autistic spectrum. The predictive coding perspective of ASD aims to extend the Bayesian framework by providing a more testable theory to facilitate experimental examination (Van Boxtel & Lu, 2013). According to predictive coding theory, a feedback loop between lower and higher brain areas allows individuals to process sensory input. Sensory input enters the brain through lower brain areas and is subsequently explained by higher brain areas using predictions about the world. In this theory, autistic symptoms are explained by an increased experience of prediction errors, a difference between the observed and expected sensory input, causing sensory overload (Van Boxtel & Lu, 2013). Van de Cruys et al. (2014) add that social processing and non-social processing should not be treated as separate, but rather different types of inferences relying on the same neural mechanism. The inability to tolerate prediction errors therefore accounts for both the social and non-social symptoms of ASD, as is set out in the comprehensive article by Van de Cruys et al. (2014). The predictive coding theory is particularly relevant in the context of early development. Van Boxtel and Lu (2013) propose that the recurring nature of predictive processing, starting from birth, can cause a cascading effect of dysfunctions.

Each of these theories attempts to explain ASD in terms of a single underlying cognitive impairment, which, considering the heterogeneous presentation of the disorder, has been widely debated (Happé, Ronald & Plomin, 2006; Pellicano, Maybery, Durkin & Maley, 2006). Although these theories, have been hugely influential and necessary steps towards a better understanding of ASD, the field is now moving towards multiple-deficits models, however, a consensus seems hard to reach. Pellicano (2011) highlights the importance of situating theoretical accounts within a developmental context, in part because of the undisputed genetic foundation of ASD.

2.5. ASD: A Genetic Disorder

After decades of research, ASD is commonly accepted in the field of neurodevelopmental disorders as one of the most heritable syndromes. The exact genetic underpinnings are still being scrutinized, since numerous specific genes and combinations of those genes seem to be involved (Abrahams & Geschwind, 2008; Glessner et al., 2009; De Rubeis et al., 2014; Jamain et al., 2003; Ronald et al., 2006; Yuen et al., 2017), as well as potential interactions with environmental factors and epigenetics (Geschwind, 2008; Persico & Bourgeron, 2006). Studies following monozygotic and dizygotic twin pairs with at least one proband diagnosed with ASD convincingly demonstrate the heritability of the disorder (Bailey et al., 1995; Colvert et al., 2015; Lichtenstein, Carlström, Råstam, Gillberg & Anckarsäter, 2010; Sandin et al., 2014; Tick, Bolton, Happé, Rutter & Rijsdijk, 2015). However, Hallmayer et al. (2011) critically note that the strong focus contemporary research has put a on the genetic factors involved in ASD potentially underestimates the effect of shared environments, in particular the prenatal environment and experiences in first year of life. The authors found a notable effect of shared environmental factors and propose these could to some extent have a significant impact on the susceptibility to ASD. Although it is widely supported that ASD has a strong genetic component, it is important not to disregard other potential factors influencing the development of the disorder, especially since environmental factors may provide opportunity for intervention.

The heritability of ASD is further demonstrated by research identifying the presence of a broader autistic phenotype (BAP) in family members who themselves have not received a formal ASD diagnosis (Losh, Childress, Lam & Piven, 2008; Pickles et al., 2000; Piven, Palmer, Jacobi, Childress & Arndt, 1997). The BAP refers to a collection of ASD symptoms that are present in both affected and unaffected family members. The symptoms are qualitatively comparable but present more mildly in unaffected family members. Several researchers have attempted to define the BAP in terms of specific behaviours and preferences. Piven et al. (1997) investigated personality and language characteristics in parents from families with multiple children with ASD and found four characteristics distinguishing such parents from controls: pragmatic language impairments, aloofness in social situations, rigidity and very few friendships providing emotional support. Similarly, Murphy et al. (2000) report increased anxiety and social difficulties in adult family members of individuals with ASD. Furthermore, in families with multiple incidences of ASD, relatives show more pronounced BAP characteristics (Losh et al., 2008).

2.5.1. A New Line of Prospective Research

Converging knowledge on the heritability of ASD has inspired a new line of research studying the infant siblings of children with ASD. Approximately 20% of infants with a diagnosed older sibling receive a diagnosis themselves at 36 months (Ozonoff et al., 2011b) relative to a 1% prevalence rate in the general population (Baird et al., 2006). Moreover, in line with research on the BAP, a substantial proportion of non-diagnosed infant siblings present with other developmental issues (Charman et al., 2017; Piven et al., 2018). Following the early development of infant siblings provides a unique opportunity to investigate the emergence of ASD prospectively, contrary to previous studies that used retrospective methods, such as parental reports and analysis of home videos which rely heavily on memory accuracy and the availability of video material (Baranek, 1999; Osterling & Dawson, 1994;

Werner, Dawson, Osterling & Dinno, 2000; Wimpory, Hobson, Williams & Nash, 2000). As noted earlier, understanding the earliest behavioural manifestations of ASD, could lead to earlier diagnosis (Koegel et al., 2014; Zwaigenbaum et al., 2015) and provides opportunities for early intervention that can significantly improve prognosis (Dawson et al., 2010; Dawson et al., 2012; Fernell, Eriksson & Gillberg, 2013; MacDonald, Parry-Cruwys, Dupere & Ahearn, 2014). Currently, ASD is not reliably diagnosed before 24 months of age (Steiner, Goldsmith, Snow & Chawarska, 2011). The median age of diagnosis in the UK is 55 months (Brett, Warnell, McConachie & Parr, 2016) and the majority of children is diagnosed after entering primary school (Hosozawa et al., 2020). Nevertheless, parents report signs of developmental delays in the second year of life (De Giacomo & Fombonne, 1998) and there is increasing evidence of deviant brain functioning in the first 12 months of life (see Elsabbagh & Johnson, 2016). Studies involving infant siblings aim to significantly lower the age of diagnosis by establishing reliable first-year markers with predictive clinical value to enable targeted intervention. I will now provide an overview of the key findings in the field of infant sibling research. All studies investigate early symptoms of ASD, but only some include outcome data to test the predictive value of the established symptoms. The latter provide important additional information about the clinical value of the proposed symptomatic markers.

2.6. Research with Infant Siblings

Over the last decade, researchers have started to explore infant sibling development in various domains, suggesting that initial symptoms emerge between 12 and 24 months of age (Bussu et al., 2018; Jones, Gliga, Bedford, Charman, Johnson, 2014; Szatmari et al., 2016). Thus far, research has predominantly focussed on social, language and motor development. This thesis is specifically concerned with socio-communicative development, however, since these areas of development are inextricably connected, I will briefly outline the other areas of development as well (for a comprehensive review see Canu et al., 2020; Jones et al., 2014; Szatmari et al. 2016).

2.6.1. Motor and Language Development in Infant Siblings

Research on early language development in infant siblings demonstrates subtle atypicalities in receptive and expressive language at the end of the first year and at the onset of the second year of life (Gamliel, Yirmiya, Jaffe, Manor & Sigman, 2009; Hudry et al., 2013; Northrup & Iverson, 2015; Paul, Fuerst, Ramsay, Chawarska & Klin, 2011; Zwaigenbaum et al., 2005). More specifically, infant siblings produce fewer speech-like vocalisations, show less vocal coordination in parent-infant interaction and present with a reduced receptive vocabulary. Other studies suggest attenuating language trajectories, with infants initially developing typically followed by a subsequent decline in language around their first birthday (Iverson et al., 2018; Longard et al., 2017; West et al., 2017). Furthermore, twelve-month-old infant siblings use fewer gestures compared to controls (Talbott & Tager-Flusberg, 2015). Parents respond to these language delays by altering their communication styles, for instance by increasing their use of gestures (Talbott & Tager-Flusberg, 2015) and showing more directive behaviour within interaction (Harker et al., 2016; Wan et al., 2012).

In addition to language delays, a number of studies have proposed delays in the motor domain. Specifically, a delayed onset of walking (Iverson & Wozniak, 2007), a head lag (Flanagan, Landa, Bhat & Bauman, 2012), as well as delays in fine and gross motor skills (Landa & Garett-Mayer, 2006; Iverson & Wozniak, 2007) have been proposed as potential early ASD symptoms, although evidence from standardized measures is mixed (Leonard, Elsabbagh, Hill & the BASIS Team, 2013). In addition to atypical language and motor development, there are some suggestions for early differences between infant siblings and typically developing infants in executive functioning (St. John et al., 2016), and repetitive behaviours and restricted interests (Elison et al., 2014), but relatively little data is available on these domains of development and results are often restricted to infants aged 12 months and older.

The areas of motor and language development hold specific relevance in relationship to each other, as novel motor acquisitions provide infants with the ability to interact with their environment in ways that facilitate language development (Iverson, 2010). Indeed, studies confirm that a considerably large group of infant siblings presenting with motor delays at 6 months develop language delays at 18 months (Bhat, Galloway & Landa, 2012; LeBarton & Iverson, 2013), illustrating a cascading pattern of developmental concerns. However, a 2017 meta-analytic review concludes that language delays are more pronounced than motor delays in the first year (Garrido, Petrova, Watson, Garcia-Retamero & Carballo, 2017). For diagnostic settings, it is essential that the intricate relationships between emerging symptoms in different areas of development are examined thoroughly. By understanding the order of emerging deviancies, intervention can be designed and delivered timely and appropriately, potentially averting a further downward spiral.

2.6.2. Social Development in Infant Siblings

Fundamentally, ASD is a socio-communicative disorder (APA, 2013) and consequently, a large body of research has investigated early social development in infant siblings. Following from the first introductory chapter on face processing and early social interaction in typical development, I will now review the literature on socio-communicative development in infant siblings, specifically focussing on face processing and early social interaction.

As became evident in Chapter 1, typically developing infants rapidly acquire novel social skills in their first year of life, building on the foundations of a demonstrated strong preference for looking at faces and face-like stimuli (Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996) and a greater attention to social versus other visual stimuli (Kelly et al., 2019; Langton et al., 2008). Furthermore, early visual attention to faces seems to be associated with later social development (Clifford & Dissanayake, 2009; Pons et al., 2019; Wagner et al., 2013). Reported deviancies in socio-communicative behaviours and social attention in young children with ASD (Chawarska & Shic, 2009; Mundy et al., 1990; Pierce et al., 2016; Webb, Dawson, Bernier & Panagiotides, 2006; Wetherby et al., 2007) drove several studies to investigate social attention and face scanning in infant siblings, presenting a pattern of mixed results. Studies examining several areas of infant sibling social development conclude that there are significant deviancies present in infant siblings. By contrast, other studies report that infant siblings develop typically in these areas, or that first-year atypicalities are not predictive of later ASD outcome.

2.6.3 Joint Attention in Infant Siblings

Similar to research studying older children with an established ASD diagnosis, several studies report findings demonstrating that infant siblings experience impairments in their initiation of and response to joint attention bids. The majority of these studies look at behaviour in the second year of life, but a small number of studies conclude joint attention deviancies during the first twelve months (Gangi, Ibanez & Messinger, 2014; Ibanez, Grantz & Messinger, 2012). These early impairments are characterised by reduced initiation of joint attention and lower positive affect during joint attention bids compared to TD infants. Gangi et al. (2014) propose that infant siblings experience difficulties with the coordination of affect and gaze and consequently engage less in joint attention behaviours. Research including older infant siblings find similar impairments in the second year of life and suggest atypicalities in both initiation and response behaviours, which are associated with later ASD outcome (Goldberg et al., 2005; Presmanes, Walden, Stone & Yoder, 2007; Yoder, Stone, Walden & Malesa, 2009). However, not all studies have reported the same impairments (Bhat, Galloway & Landa, 2010; Goldberg et al., 2005), and there is an absence of clarity surrounding infant sibling performance on gaze following, a precursor to joint attention. Thorup et al. (2018) conclude impairments in gaze following at ten months is associated with later ASD symptoms, whereas Bedford et al. (2012) present findings suggesting gaze following is typical in 13-month-old infant siblings.

2.6.4 Parent-infant Interaction in Infant Siblings

Various recent studies have also examined infant sibling behaviour within a social interaction with their parent to study early social engagement and reciprocity. This is particularly relevant to study, as studies with older children with ASD highlight the importance of early dyadic behaviour for later social responsiveness (Clifford & Dissanayake, 2009). Collectively, studies including infant siblings converge to conclude social impairments emerging at 12 months, but not earlier (Ozonoff et al., 2010; Rozga et al., 2011; Yirmiya et al., 2006). For instance, 12-month-old infant siblings present with reduced social engagement levels and gesture use, as well as a delayed development of vocalisations during parent-infant interaction, which is associated with ASD outcome at age 3 (Campbell, Leezenbaum, Mahoney, Day & Schmidt, 2015; Heymann et al., 2018; Paul et al, 2011; Rozga et al., 2011; Talbott et al., 2015; Wan et al., 2013). Furthermore, during interaction infant siblings tend to show fewer gazes to faces and display fewer shared smiles compared to TD infants (Harker et al., 2016; Ozonoff et al., 2010; Rozga et al., 2011), consistent with parental reports at 12 months of age (Barbaro & Dissanayake, 2012). However, two studies examining early interaction report no differences in social behaviour between infant siblings and TD controls at 12 months (Hutman, Chela, Gillespie-Lynch & Sigman, 2012; Steiner, Gengoux, Smith & Chawarska, 2018), although publication bias may have affected the publication of no-difference findings (Ferguson & Heene, 2012). Additionally, several studies probing early interaction have also included parameters of parental behaviour to examine whether the social input infant siblings receive differs from their TD counterparts. Collectively, it is concluded that parents of infant siblings and parents of TD infants are equally socially responsive and provide similar levels and quality of linguistic input during interaction with their infant (Harker et al., 2016; Leezenbaum, Campbell, Butler & Iverson, 2014; Schwichtenberg, Kellerman, Young, Miller & Ozonoff, 2018; Talbott, Nelson & Tager-Flusberg, 2016). Nonetheless, parents of infant siblings display higher levels of directive behaviour (Harker et al., 2016; Wan et al., 2012), which is interpreted as an active parental attempt to engage their less engaged infant (Steiner, 2018). This suggests that parents are sensitive to their infant's reduced social engagement levels and consequently, they adopt a more directive communication style, although the exact details of how parent and infant behaviour affect each other remain unclear. Lastly, standardised measures of social behaviour confirm early impairments during social interaction (Gammer et al., 2015; Yoder et al., 2009).

2.6.5 Face Scanning in Infant Siblings

Returning to face scanning, an important foundational skill for later social behaviour (e.g. Pons et al., 2019), the evidence again seems to show a mixed pattern of results. Several eye-tracking studies without long term outcome data report subtle deviancies in face scanning strategies in infant siblings. Predominantly, these studies present data from infants aged 6 months and older, but there is one study suggesting that deviancies in visual preference to social stimuli are already present in newborns (DiGiorgio et al., 2016). Merin, Young, Ozonoff and Rogers (2007) report that 6-month-old infant siblings show decreased gaze to their mother's eyes relative to the mouth during a still face procedure, although other studies conclude that increased mouth looking in infant siblings is positively associated with later language development (Elsabbagh et al., 2014; Young, Merin, Rogers & Ozonoff., 2009). Additional behavioural measures during the still face procedure suggest atypical affect and attentional engagement (Cassel et al., 2007; Ibanez, Messinger, Newel, Lambert & Sheskin, 2008). Guiraud et al. (2012) conclude that 9-month-old infant siblings spent less time overall attending to faces compared to TD infants when presented with videos of faces making speech sounds. However, a further three studies including similar age groups report no differences in face scanning patterns between infant siblings and TD infants (Key & Stone, 2012; Kleberg, Nyström, Bölte & Falck-Ytter, 2018; Dewaele, Demurie, Warreyn & Roeyers, 2015), all three studies employing static images of faces as stimuli. From the six studies that do include ASD outcome data, three report typical face scanning strategies and attentional responses in infant siblings (Elsabbagh et al., 2013; Elsabbagh et al., 2014; Wagner, Lusyter, Moustapha, Tager-Flusberg & Nelson, 2018), and one study concludes differences in gaze behaviour are not predictive of later ASD (Young et al., 2009) using both static and dynamic faces as stimuli. Contrastingly, two studies presenting talking faces as stimuli do report deviant face scanning patterns are indicative of later ASD (Chawarska, Macari & Shic, 2013; Shic, Macari & Chawarska, 2014). Additionally, there is research suggesting gender differences in infant siblings' attentional responses to faces (Chawarska, Macari, Powell, DiNicola & Shic, 2016; Kleberg et al., 2018) with female infant siblings demonstrating typical or heightened social attention. Evidently, there is no clear consensus on the presence and nature of potential face scanning deviancies in infant siblings.

2.6.6. Moving the Field Forward

Taken together, although this large body of research examining the early socio-communicative development of infant siblings has progressed the field, the pattern of mixed results at best provides a tentative proposition for a reliable first-year marker. Paradoxically, neurological research does consistently confirm deviancies in brain responses towards faces and social scenes, in 4- to 14-month-old infant siblings later diagnosed with ASD (Elsabbagh et al., 2009; Elsabbagh et al., 2012; Key et al., 2015; Lloyd-Fox et al., 2013; Orekhova et al., 2014), despite a lack of consistency in behavioural results. What is the cause of this discrepancy between neurological and behavioural research results in the first year of life? How can a reliable, behavioural, first-year marker of ASD symptomology be established? Considering the cost and effort associated with neuroimaging, it seems unfeasible to offer neurological screening as a preventative measure to every infant at familial risk for ASD. Therefore, it is essential that future research aims to uncover a scalable behavioural marker with clinical utility.

In this thesis, I argue that the methods behavioural eye-tracking studies have employed to date are lacking in their ability to detect early social deviancies due to oversight of the contingency and reciprocity intrinsic to social interaction. Thus far, research into early socio-communicative behaviour has used *non-interactive* stimuli, such as images and videos of faces, to study processes that are inherently interactive. These stimuli do not capture the contingency and reciprocity inherent to the social context in which face scanning occurs. For studies focussing exclusively on typical development, the use of inadequate stimuli means that the extent to which they produce findings that generalize to 'real world' social interactions is unclear. For the line of research involving infant siblings, these methodological issues have resulted in an ambiguous pattern of results. This notion is corroborated by a recent paper by Bussu et al. (2018) that integrated multiple behavioural and developmental measures and demonstrated using machine learning that an ASD diagnosis can be predicted with only moderate accuracy at 14 months. In this paper, the authors highlight that the lack of predictability in the first year of life could be due to the inability of current tools to capture ASD-related manifestations on social skills at early age. Consequently, it is concluded that future studies must employ methods that are sufficiently socially demanding in order to advance the field.

2.7. Structure of this Thesis

Despite rigorous attempts, a reliable first-year marker remains elusive and researchers are faced with an unresolved puzzle. As well as contributing to the literature on typical development in order to make findings on social attention more generalizable, this thesis attempts to address the first-year puzzle by introducing a novel research paradigm that more closely approximates the interactive context in which face scanning typically occurs.

To overcome the demonstrated methodological issues, Chapter 3 will introduce the gaze-contingency paradigm, a novel research method in which infants are presented with interactive, gaze-contingent faces on a computer screen. Infants are provided with an interactive experience as responses from the viewed faces are contingent on infants' unique eye movements. Fixating different parts of the presented face will result in different social responses directed at the infants (*e.g.* fixating the eye area triggers a smiling response from the face). Eye-tracking data and video recordings of infant behaviour will be collected. This first experimental chapter will test the efficacy of the novel paradigm with a large sample of typically developing infants, as well as establishing norms for typical behaviour. Additionally, preliminary findings of a small sample of infant siblings will demonstrate the potential of the paradigm to detect early atypical social development.

Chapter 4 will build on Chapter 3 by further developing the gaze-contingency paradigm and including novel stimuli that present infants with one of the six basic expressions (happiness, anger, surprise, fear, disgust and sadness; Ekman, 1973) provided that they engage in eye contact with the viewed face. This chapter also comprises a larger sample of infant siblings to examine the ability of the novel paradigm to distinguish between infant siblings and TD infants. Following from earlier research on parent-infant interaction in infant siblings, Chapter 5 examines the relationship between infant sibling performance on the gaze-contingent task from Chapter 4 and behaviour during a parent-infant free play task. It is explored if behaviour during the interactive eye-tracking task extends to a real-life interaction.

After probing social interactions in which the infant was an active interaction partner, Chapter 6 examines what infants understand about social interactions between two others that they experience as a viewer. Social development does not only involve 'becoming an active interaction participant', but also includes the acquisition of knowledge about other people's interactions. Infants' ability to follow everyday conversations will be explored in a large typically developing sample. This chapter will again aim to improve previous methods by introducing novel cartoon stimuli. The findings from these four experimental chapters will be further discussed in the final chapter, Chapter 7, in which limitations are considered and suggestions for further research are provided.

Chapter 3

Infants' Responses to Interactive Gaze-Contingent Faces in a Novel and Naturalistic Eye-Tracking Paradigm

Introduction

The introductory chapters to this thesis provided an overview of face processing and socio-communicative behaviour in the first year of life and introduced the line of research that investigates infants at risk for atypical social development. I argued that the methods employed by previous studies might not be sufficiently interactive to accurately reflect face processing as it occurs within in the real world (i.e. during face-to-face social interactions). This first experimental chapter will introduce a novel research paradigm capable of capturing the contingency and reciprocity inherent to the social context in which face processing naturally occurs.

Faces represent a stimulus category of unique importance generating greater attention compared to other visual stimuli (Kelly et al., 2019; Langton et al., 2008). Newborn human infants show a preference for faces and face-like stimuli (Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996), recognise and prefer their mother's face (Bushnell et al., 1989; Pascalis et al., 1995), and favour attractive faces (Slater et al., 1998). Infants show particular interest in the eye region (Di Giorgio et al., 2013; Haith et al., 1977; Maurer & Salapatek, 1976) and from birth engage in and actively search for mutual eye gaze (Farroni et al., 2002). There is a rapid increase in attention to faces between 3 and 11 weeks of age (Haith et al., 1977) with an eye preference present in 6-week-old infants (Hunnius & Geuze, 2004). Several studies report a subsequent decrease in eye region attention from 6-12 months of age (Lewkowicz & Hansen-Tift, 2011; Tenenbaum et al., 2012) with infants shifting their focus to the mouth region, attributed to language learning. Similarly, Oakes and Ellis (2013) demonstrated an eye preference in 4.5 to 6.5-months-old infants and more distributed looking in older 8- to 12-months-old infants. Collectively, these studies have provided insights into face scanning throughout the first year of life, yet the extent to which their methodologies produce findings that generalize to 'real world' social interactions is unclear.

When infants encounter faces outside of the lab, this takes place in a highly interactive, social context in which reciprocity and contingency play a crucial role. However, past studies have attempted to answer questions about face-to-face *interactions*, whilst using methods that employ *non-interactive* stimuli. Although previous methods present infants with facial stimuli, such as static images (Di Giorgio et al., 2013; Oakes and Ellis, 2013), videos of faces (Hunnius and Geuze, 2004; Lewkowicz & Hansen-Tift, 2011; Tenenbaum et al., 2012) and real faces (Haith et al., 1977; Maurer & Salapatek, 1976), these stimuli do not capture the reciprocity inherent to the social context in which face scanning occurs. By reducing face scanning to an isolated skill, we lose the richness and meaningfulness of the interactive context. In order to overcome this methodological issue, the current study introduces a novel eye-tracking paradigm in which infants are presented with interactive, gaze-contingent faces whilst their behavioural responses (e.g. smiles, head shaking) towards the interactive faces are measured.

The Gaze-contingency Paradigm

Advances in eye-tracking permit the fine-grained study of infants' responses to visual stimuli and enable the implementation of novel and interactive gaze-contingency paradigms. In gaze-contingency paradigms the participant's viewing experience is contingent upon their eye movements, which allows the participant to 'interact' with stimuli providing a more naturalistic and interactive experience. A small number of studies have indicated that gaze-contingency paradigms can be effectively implemented in adult and infant research (Deligianni, Senju, Gergely & Csibra, 2011; Miyazaki, Takahashi, Rolf, Okada & Omori, 2014; Wang et al., 2012; Wilms et al., 2010). Furthermore, previous research has established that from 2 months of age, infants are sensitive to and are capable of learning visual (De Schonen & Bry, 1987; Johnson, Posner & Rothbart, 1991), social (Rochat et al., 1999; Soussignan et al., 2006) and physical contingencies (Alessandri, Sullivan & Lewis, 1990; Angulo-Kinzler, Ulrich & Thelen, 2002; Rovee & Rovee, 1969). Face scanning lends itself perfectly for gaze-contingency paradigms because of its interactive nature. However, surprisingly, there are no published studies to date investigating face scanning using gaze-contingency paradigms.

The current study comprises a novel and unique combination of gaze-contingent eye-tracking and behavioural measures designed to capture social interaction in a controlled lab environment and to establish the efficacy of this paradigm within infant face scanning research. The task will simultaneously provide measures of initial fixation location, contingency learning, face scanning and behavioural responses (i.e. reciprocity). Furthermore, by testing a large sample of typically developing (TD) infants, ranges of typical behaviour will be established. In addition to contrasting groups, a distribution-based approach provides the opportunity to explore and establish the ranges of typical within a gaze-contingency paradigm. Contrary to previous studies that have explored face processing strategies in only one age group (Young et al., 2009), and with limited sample sizes (e.g., Klin, Jones, Schultz, Volkmar & Cohen, 2002), the current study sample comprised 6-, 9-, and 12-month-olds (*n* = 162).

For the task, participants sequentially viewed a series of video-recorded actors that could produce either a socially engaging or a socially disengaging response, which was contingent on first fixation location. Based on existing face scanning research (e.g., Di Giorgio et al., 2013), it was hypothesized that infants would be likely to initially fixate the eye region. However, previous findings (e.g., Soussignan et al., 2006) also led to the hypothesis that infants might be capable of learning the task contingency and consequently would favour triggering socially engaging responses. Finally, infants' faces were video recorded throughout testing. Infants were expected to show behaviour congruent with the triggered response from the actors (e.g., a smile for a smile) (Hains & Muir, 1996).

The novel, interactive nature of the gaze-contingent stimuli produces a more socially demanding task compared to previous methods, which lead to the believe that eventually the task could be employed to explore early signs of atypical social development. A recent line of research has focussed on the infant siblings of children with autism spectrum disorder (ASD). These infants are at elevated familial risk to receive a diagnosis themselves, and ASD prevalence within this subgroup is 20% relative to 1.5% in the general population (Ozonoff, 2011; Szatmari et al., 2016), allowing for the prospective investigation of the development of ASD. Several studies looking at face scanning in infant siblings suggest some deviancies (Chawarska et al., 2013; Guiraud et al., 2012; Shic et al., 2014; Merin et al., 2007), although Young et al. (2009) report that these are not related to later ASD outcomes. However, these studies employ *non-interactive* stimuli similar to the aforementioned research. In contrast to any previously published research, the current research design will enable the exploration of discrete social interactions within a controlled laboratory setting by synthesizing fine-grained eye movement analyses with overt behavioural reactions, permitting more meaningful conclusions about face scanning in typical and atypical populations. Therefore, for exploratory purposes a small sample of infant siblings will be included and compared to the established behavioural norms for the typical population.

Method

This study was approved by the Ethics Committee of the University of Kent (Protocol number: 20153600, Project name: Social Interaction preferences and visual face scanning strategies in 6- to 12-months-olds: evidence from a gaze-contingency paradigm). All parents signed an informed consent for their participating infant. Data were stored and treated anonymously.

Participants

Typically developing infants were recruited through the Kent Child Development Unit database of families who have enlisted for research. Infants were considered typically developing if they had no known medical/psychological conditions. The final sample consisted of 162 infants (79 male, 83 female), who were separated into three different age groups: 6-month-olds, 9-month-olds and 12-month-olds (See Table 1). All infants were Caucasian. Infants were randomly assigned to either the *Social Eyes* (*SE*) condition (n = 89) or the *Social Mouth* (*SM*) condition (n = 73). A further 16 infants participated in the SM condition but disengaged from the task. Eleven infants in the sample were classified as infant sibling, as they had an older sibling with a formal diagnosis. They were recruited through autism support groups across Kent.

After group analyses were conducted on the total sample, the performance of individual infant siblings was explored. Previous research looking at early markers for ASD has contrasted an infant sibling sample with a TD sample to examine group differences. In addition to investigating group differences, it is proposed that it might be meaningful to examine individual infant sibling behaviour compared to ranges of typical behaviour. Arguably, infant siblings do not constitute a separate group (yet), as only ~20% of them will receive an ASD diagnosis (Ozonoff et al., 2011b). It is that subgroup that potentially will differentiate from the typical range on sufficiently sensitive measures.

The Gaze-Contingent Task

The gaze-contingent task consisted of a series of video-recorded actors who could produce a response of low or high social engagement (closed/open smile), or a response of low or high social *dis*engagement (closing eyes/looking away) contingent on the infant’s first fixation location. The socio-communicative behaviour produced by the actors was contingent on the infant’s eye movements and was triggered by engaging in eye contact or by fixating on their mouth (See Figure 1). The animation was activated by the first fixation landing in either of these regions. Both socially engaging and disengaging responses were included to explore whether infants were motivated to seek out a socially engaging response, and to investigate a potential difference in behavioural responses from the infants towards social engagement and social disengagement. In the *SE* condition, infants triggered socially engaging responses by fixating the eyes and socially disengaging responses by fixating on the mouth. Responses were reversed in the *SM* condition; fixating the eyes resulted in a socially disengaging response and fixating the mouth in a socially engaging response (See Figure 2). If an infant did not fixate on one of the discrete regions within the trial-length, the face would not animate and remain looking neutral.

Table 1

Participant Characteristics per Age group and Condition

	Age in Months	*Condition*	*N*	*Mean Age in Days (SD)*	*Age Range*	*Gender (M/F)*
TD	6	SE	29	198 (4.8)	187 - 206	(12/17)
		SM	21	199 (4.5)	188 - 209	(10/11)
	9	SE	29	279 (9.1)	263 - 303	(13/16)
		SM	24	280 (7.7)	266 - 293	(13/11)
	12	SE	28	370 (9.4)	354 - 387	(14/14)
		SM	20	371 (9.1)	354 - 388	(8/12)
HR	6	SE	-	-	-	-
		SM	3	190 (2.1)	188 – 192	(3/0)
	9	SE	1	283 (N/A)	N/A	(1/0)
		SM	-	-	-	-
	12	SE	2	367 (10.6)	360 - 375	(2/0)
		SM	5	370 (5.6)	362 - 377	(3/2)
Total		SE	89			(42/47)
		SM	73			(37/36)

Note: TD refers to typically developing infants, HR refers to high risk (infant siblings)

Description of Stimuli

The stimuli were 20 colour videos of ten neutral-looking male and female adult faces visible from the shoulders upward standing in front of a green screen (See Figure

1). Each stimulus appeared twice and in consecutive trials to assess if learning occurred across presentations. Each trial lasted five seconds. Eight faces were of Caucasian origin and two faces of African origin. All images subtended a size of 24.77 degrees x 18.25 degrees in visual angle and were presented on a 20-inch monitor with a resolution of 1024 by 768 pixels. Discrete gaze-contingent 'invisible boundaries' for eye and mouth regions were defined individually for each face (See Figure 1). All eye regions measured 6.8 x 2.83 degrees and all mouth regions measured 5.06 x 2.83 degrees. A dissimilarity in AOI size is common practice in infant face scanning research (e.g. Chawarska et al., 2013; Wagner et al., 2016), and the potential impact of this difference will be considered below in the results section

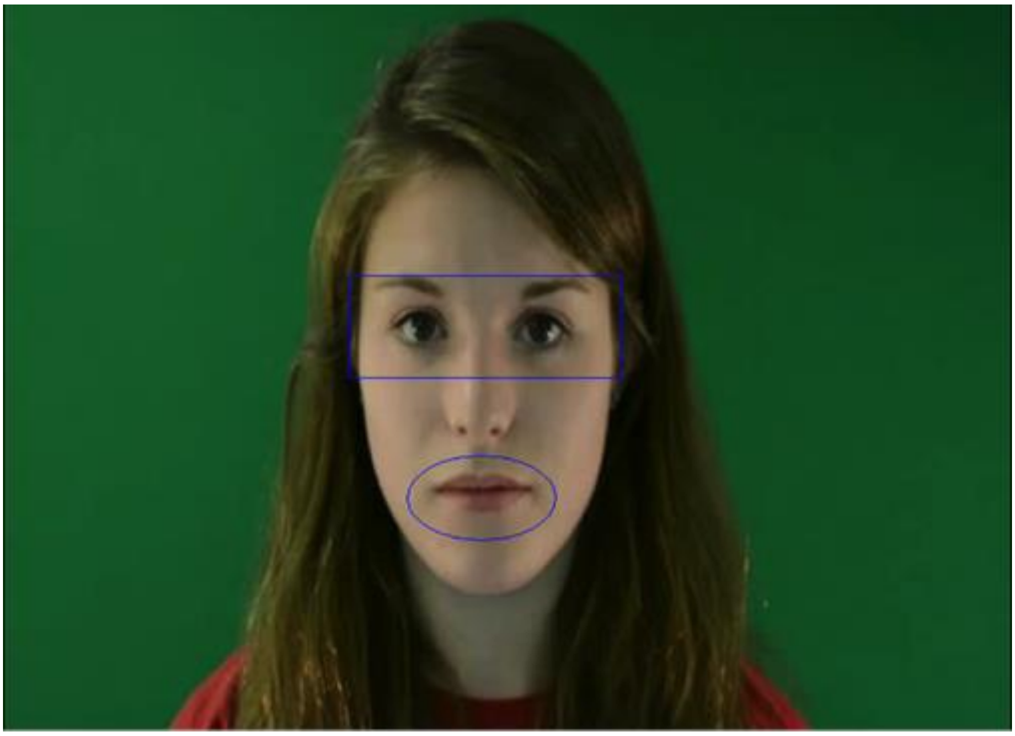


Figure 1. A Stimulus with the Discrete Eye and Mouth Regions Visible.

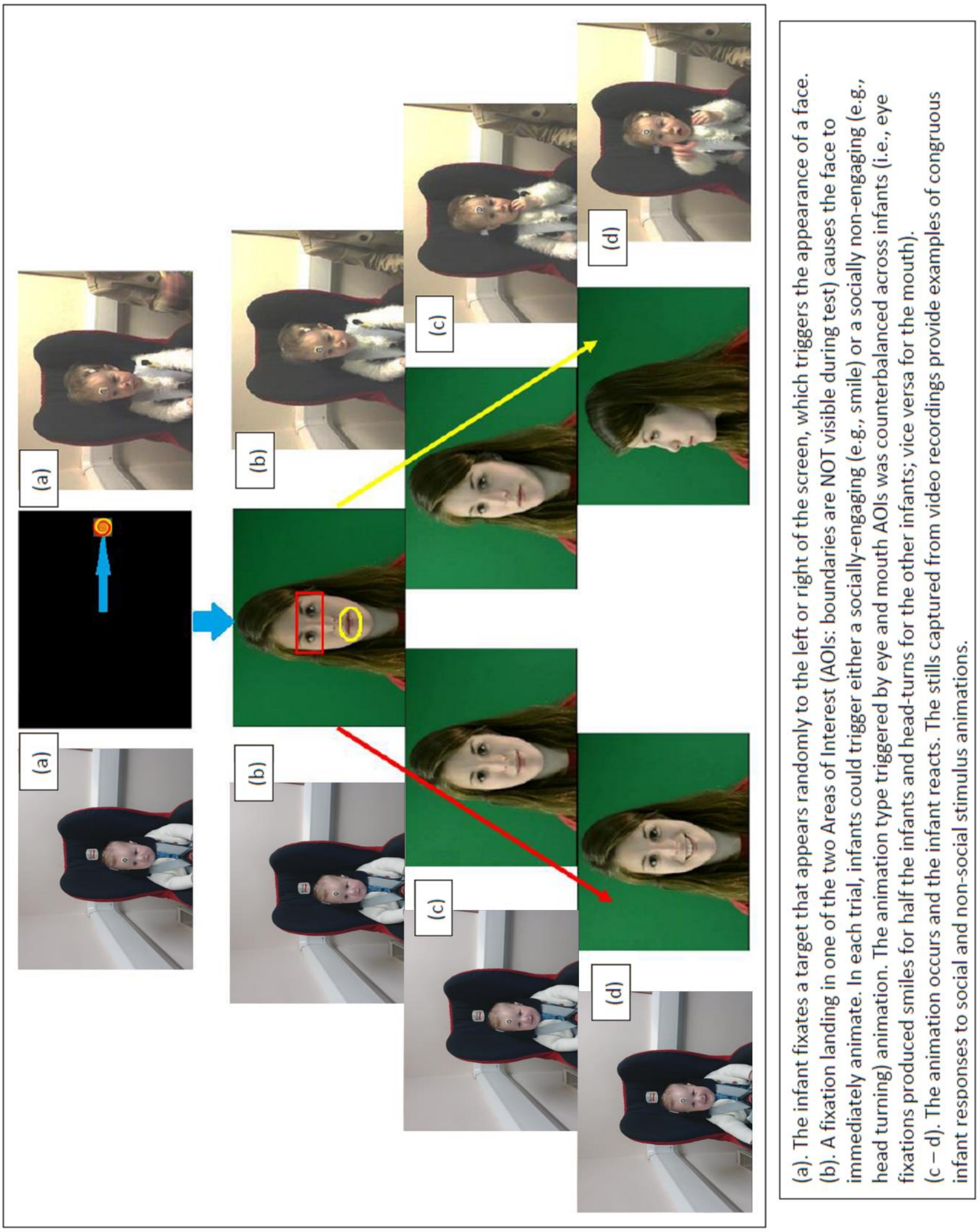


Figure 2. Examples of Socially-Engaging and Socially-Disengaging Animations with Accompanying Infants’ Behavioural Responses.

Equipment

Eye movements were recorded with an Eyelink 1000+ (SR Research, Ontario) at a sampling rate of 500 Hz operated in Remote Mode using a 25mm lens attachment. Infants aged 12 months were tested using the 890 nm illuminator, while all other age groups were tested using the 940 nm illuminator. Under optimal conditions, when operating in Remote Mode the Eyelink has accuracy of 0.5°, a tracking range of 32° (horizontal) x 25° (vertical) and is tolerant to head movements of 22x18x20cm. In order to minimise head movements, infants were securely fastened in an age-appropriate car seat that was safely attached to a chair. Stimuli were presented using Experiment Builder (SR Research, Ontario) and the raw eye movement data were extracted using Data Viewer (SR Research, Ontario). Fixations and saccades were subsequently parsed in Matlab (The Mathworks, MA, USA) using custom written code.

In addition, infants' behavioural responses were recorded with a Logitech webcam. Recordings were analysed frame-by-frame and coded by one of the researchers and an independent coder (see below). Overall, agreement between the coders was .94. Coder agreements per specific response types were as follows: positive, $r = .96$; negative, $r = .93$; ambiguous, $r = .92$; and no response = .97.

Procedure

Families were welcomed and informed about the study. Parents were asked to sign a consent form and then escorted to the research laboratory with dimmed lighting. Infants were placed in an age-appropriate seat at a viewing distance of 60cm from a computer monitor. The infant's right eye was tracked throughout testing. Additionally, behavioural responses were video recorded throughout. The infant's view to their surroundings and experimenters was obstructed by an occluding screen. A 5-point calibration procedure using custom-made attention-grabbing audio-visual targets (Supplied by Dr. David Meary, Université Grenoble-Alpes) was conducted and repeated as necessary. To ensure that all eye movement data was accurate, all infants were calibrated and validated to within 1° and checks for drift were assessed between every single trial. No infant failed to calibrate. Following calibration, the task was initiated. An attention grabber appeared at the side of the screen between each stimulus presentation that ensured the infant's gaze for the beginning of each trial. The study lasted approximately five minutes. After participation, infants received a young scientist certificate and a small age-appropriate gift.

Eye Movements

A velocity-based algorithm was used to identify saccades. Data was initially smoothed by applying a 4-sample rolling window that returned a median average. Angular speed was computed based on 4 samples. Velocity values greater than 1000°/sec were judged to be impossible and were removed from analysis. A velocity threshold of 40°/sec was set, with samples falling below this value identified as potential fixation samples. Time and distance between 2 potential fixations were calculated. If inter-fixation values were <20ms and <.03° then fixations were merged. All fixations <100ms were removed. All subsequent data processing was conducted in Matlab (using code provided by PhD supervisor).

Behavioural Coding

Video-recorded behavioural responses were categorized as positive, negative, ambiguous or a non-response. Smiling, waving, giggling, cheerful vocalizing and cheerful pointing were seen as positive responses. Negative responses comprised looking away, vocalizing, frowning, head shaking and sad facial expressions with some of the older infants showing more complex behaviours such as indignant pointing. Some responses fell in-between categories and were coded as ambiguous (e.g. arbitrary head movements). If an infant maintained a neutral facial expression throughout the trial, the trial was coded as 'no response'.

Subsequently, eye movement data were time-locked with the behavioural data to ensure the infant's behaviour occurred in *response* to the triggered animation and to examine whether the behaviour was congruent or incongruent with the triggered animation. Congruent responses comprised a positive behaviour from the infant towards an actor's socially engaging response or a negative behaviour from the infant towards an actor's socially disengaging response. Conversely, incongruent responses comprised a positive behaviour towards a socially disengaging response or a negative behaviour from the infant towards a socially engaging response (See Figure 2 for examples of congruent responses).

Results

As aspects of the methodology of this study are completely novel, it was not possible to conduct accurate *a priori* power analyses, but *post-hoc* power analyses indicated very high power (.88 - .99) for all main effects and interactions with the exception of the Condition x Response interaction effect for behavioural responses, which was notably low (.15). Preliminary analyses indicated no differences of participant gender, so it was omitted for further analyses. Ethnicity and stimulus gender did not affect any infant responses, nor did face repetition. Eye-movement analyses will first be described covering overall AOI dwell time followed by explicit (i.e. the percentage of fixations triggering socially engaging responses) and implicit (i.e. saccadic response times across trials) measures of contingency learning. Behavioural responses will subsequently be assessed. Data will be analysed with 3 (Age: 6, 9 or 12 months) x 2 (Condition: SE or SM) x 2 (AOI: Eyes or Mouth) ANOVAs and appropriate post-hoc tests unless stated otherwise. Finally, Z-normalized ranges of typical behaviour on key dependent measures will be assessed and the performance of a small sample of infant siblings will be contrasted with typical norms.

Eye-movement Data

Overall AOI Dwell Time. The independent measures for these analyses are age, condition and AOI. The dependent measure is overall percentage of fixations.

Analyses were conducted to examine whether dwell time to eyes and mouth (cumulative time following animation trigger) differed by condition and/or age. A univariate ANOVA revealed a significant effect of *Condition* ($F(1,312) = 7.100$, $p = .008$, $\eta_p^2 = .022$), a main effect of *AOI* ($F(1,312) = 389.828$, $p < .001$, $\eta_p^2 = .555$) and a significant *Condition x AOI* interaction ($F(1,312) = 9.105$, $p = .003$, $\eta_p^2 = .028$). Inspection of means confirmed that eyes were fixated more (SE = 39.24%; SM =

39.71%) than the mouth (SE = 17.86%; SM = 10.57%) by infants of all ages and regardless of condition.

In order to ensure that frequency of trigger AOI responses was not driven by the differences in AOI sizes between the eyes and mouth, a univariate ANOVA was also conducted on data that was corrected to account for the difference in pixel space. When calculated as a percentage of the face stimulus, the eye region occupies 4.25% of the stimulus pixel space and the mouth occupies 3.16% of the pixel space. To correct for this discrepancy, the percentage of eye triggers was divided by 4.25 and the percentage of mouth triggers was divided by 3.16. This was conducted at an individual participant level. This process produced the following mean values (*SE* eyes: eyes 16.81, mouth: 5.78 and *SM* eyes: 15.26, mouth: 4.87%). Similar to the uncorrected analysis, a univariate ANONA revealed a main effect of AOI ($F(1,312) = 303.345$, $p < .001$, $\eta p^2 = .493$) and a significant Age x AOI interaction ($F(2,312) = 4.898$, $p = .008$, $\eta p^2 = .030$).

Independent t-tests confirmed that dwell time did not differ between conditions for Eyes ($t(160) = -.2588$, $p = .797$). However, the mouth was fixated significantly more ($t(160) = 3.889$, $p < .001$) by infants in the *SE* condition than the *SM* condition (See Table 2 for a breakdown of percentages of fixations per AOI, condition and age). Although seemingly counterintuitive, this finding can be accounted for by the tendency for infants to look directly at the mouth once a smile was initiated (See Figure 3).

Separate analyses for dwell time on eyes and mouth yielded a significant effect of age on dwell time on the eye area ($F(2,159) = 4.080$, $p = .019$, $\eta_p^2 = .049$), but not for the mouth area ($F(2,159) = 1.303$, $p = .275$, $\eta_p^2 = .016$). Post-hoc analyses revealed differences between 6- and 12-month-olds only (p = .005), with 6-month-olds fixating the eye area more (M = 42.25%) relative to 12-month-olds (p = 36.20%).

Table 2

Mean Percentage of AOIs Fixated Post-trigger Onset

Condition	*Age (in months)*	*Eyes (%)*	*Mouth (%)*	*Outer (%)*
SE	6 (N = 29)	44.04 (8.93)	14.98 (9.26)	40.96 (8.02)
	9 (N = 30)	38.02 (10.15)	20.19 (13.92)	41.78 (9.87)
	12 (N = 30)	35.81 (10.09)	18.31 (13.07)	45.87 (13.51)
	Total (N = 89)	39.24 (10.24)	17.86 (12.33)	42.87 (9.68)
SM	6 (N = 24)	40.08 (12.54)	9.15 (7.23)	50.76 (6.69)
	9 (N = 24)	42.50 (11.76)	9.44 (10.78)	48.04 (11.39)
	12 (N = 25)	36.65 (13.39)	13.01 (14.51)	50.33 (10.88)
	Total (N = 73)	39.71 (15.28)	10.57 (9.39)	49.71 (11.52)

Explicit Contingency Learning: First Fixation Location. Explicit contingency learning would be demonstrated if across trials infants' first fixations more frequently fell within the area that produced a socially engaging response (eyes for the *SE* condition, mouth for the *SM* condition). This would indicate that infants had learned what area to fixate in order to trigger social engagement. The independent measures for these analyses are age, condition and AOI (mouth vs. eyes). The dependent measure is the percentage of first fixations.

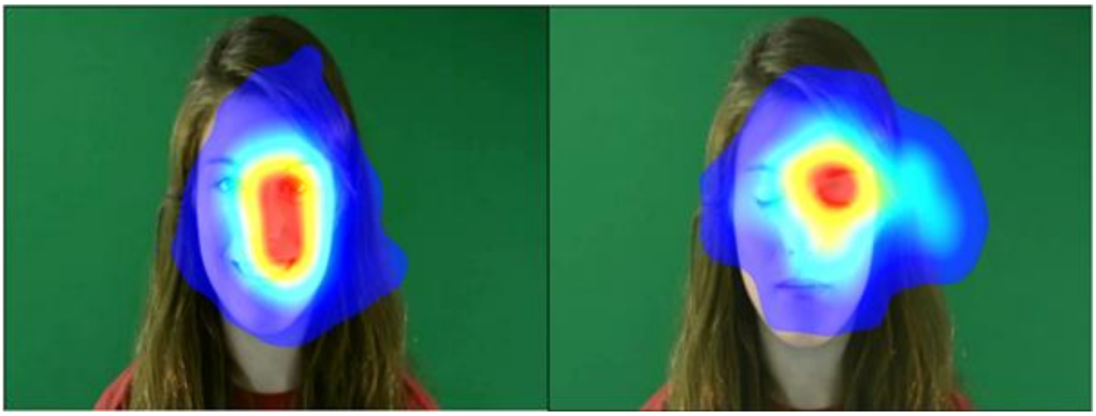


Figure 3. Summed fixations post-animation onset for all infants in the *SE* condition on the left and *SM* condition on the right. The tendency for infants to fixate the mouth (smile) in the *SE* condition but not in the *SM* condition is clearly visible.

A univariate ANOVA revealed a main effect of AOI ($F(1,312) = 533.842$, $p < .001$, $\eta_p^2 = .631$) and a significant Age x AOI interaction ($F(2,312) = 6.567$, $p = .002$, $\eta_p^2 = .040$). Regardless of condition and age, infants were far more likely to initially fixate the eyes relative to the mouth (*SE* eyes: 71.48%, mouth: 18.28% and *SM* eyes: 69.21%, mouth: 15.41%). Post-hoc one-way ANOVAs revealed significant Age differences for Eyes only, with significant differences between 6- and 12-month-olds ($p = .003$); 12-month-olds displayed fewer eye fixations ($M = 62.20$) relative to 6-month-olds ($M = 75.33$). However, regardless of age or condition, infants showed a clear tendency to initially fixate the eyes relative to the mouth. Evidence for explicit contingency learning was not found.

Implicit Contingency Learning: Saccadic Latencies. In addition to explicit contingency learning, implicit contingency learning was investigated. Analyses were conducted on saccadic response times to trigger the face animations. It was reasoned that, as an implicit response from the infant to the two different social responses of the actors, infants could become more eager (faster saccades) or more reluctant (slower saccades) to trigger the animations. Infants in the *SE* condition would demonstrate implicit contingency learning if their saccadic response times in trials 11-20 were *faster* relative to trials 1-10 as a result of the socially engaging responses. Infants in the *SM* condition demonstrated implicit contingency learning if their saccadic response times in trials 11-20 were *slower* relative to trials 1-10 because of the socially disengaging responses.

Saccadic response times to trigger the animation were calculated and the saccadic response times for trials 1-10 and trials 11-20 were contrasted, as previous studies have indicated that infants show evidence of learning within 10 trials (e.g., Colombo, Mitchell, Coldren & Atwater, 1990; Fawcett & Liszkowski, 2012; Hauf & Aschersleben, 2008). The independent measures for these analyses are trials (1-10 vs. 11-20) and condition. The dependent measure is the saccadic response time (in seconds) it took infants to trigger the animation. (N.B. Animations could be triggered by fixating either the eye or the mouth area, so the dependent measure comprises saccades to either of these areas. In reality, saccades more often were directed to the eye area as demonstrated in the section on first fixation location).

Preliminary analyses demonstrated no overall significant differences in saccadic response time between conditions ($F(1,150) = 1.056$, $p = .795$, $\eta_p^2 < .001$). Subsequently, a 2 (Trials) x 2 (Condition) repeated measures ANOVA was conducted on the saccadic response times split across trials 1-10 and trials 11-20. The ANOVA yielded a significant Trials x Condition interaction ($F(1,156) = 9.724$, $p = .002$, $\eta_p^2 = .059$). Inspection of means revealed that saccadic response times did not differ between conditions for trials 1-10 (*SE* = 693 msecs, *SM* = 651 msecs), but they differed substantially for trials 11-20 (*SE* = 605 msecs, *SM* = 712 msecs).

Further two-tailed *t*-tests confirmed implicit contingency learning as summarized in Figure 4. Independent-samples *t*-tests analysing differences in response times revealed no difference between conditions for trials 1-10 ($t(160) = .938$, $p = .35$), whereas for trials 11-20 infants in the *SE* condition demonstrated significantly faster saccades compared to infants in the *SM* condition as a result of socially engaging and socially disengaging responses respectively ($t(160) = -2.660$, $p = .009$). Additionally, paired-samples *t*-tests analysing differences between trials 1-10 and trials 11-20 within conditions, revealed a significant difference for the *SE* condition only ($t(88) = 2.711$, $p = .008$). Infants in the *SE* condition showed significant faster saccades on trials 11-20 compared to trials 1-10, whereas there was no difference for the *SM* condition ($t(72) = -1.690$, $p = .094$).

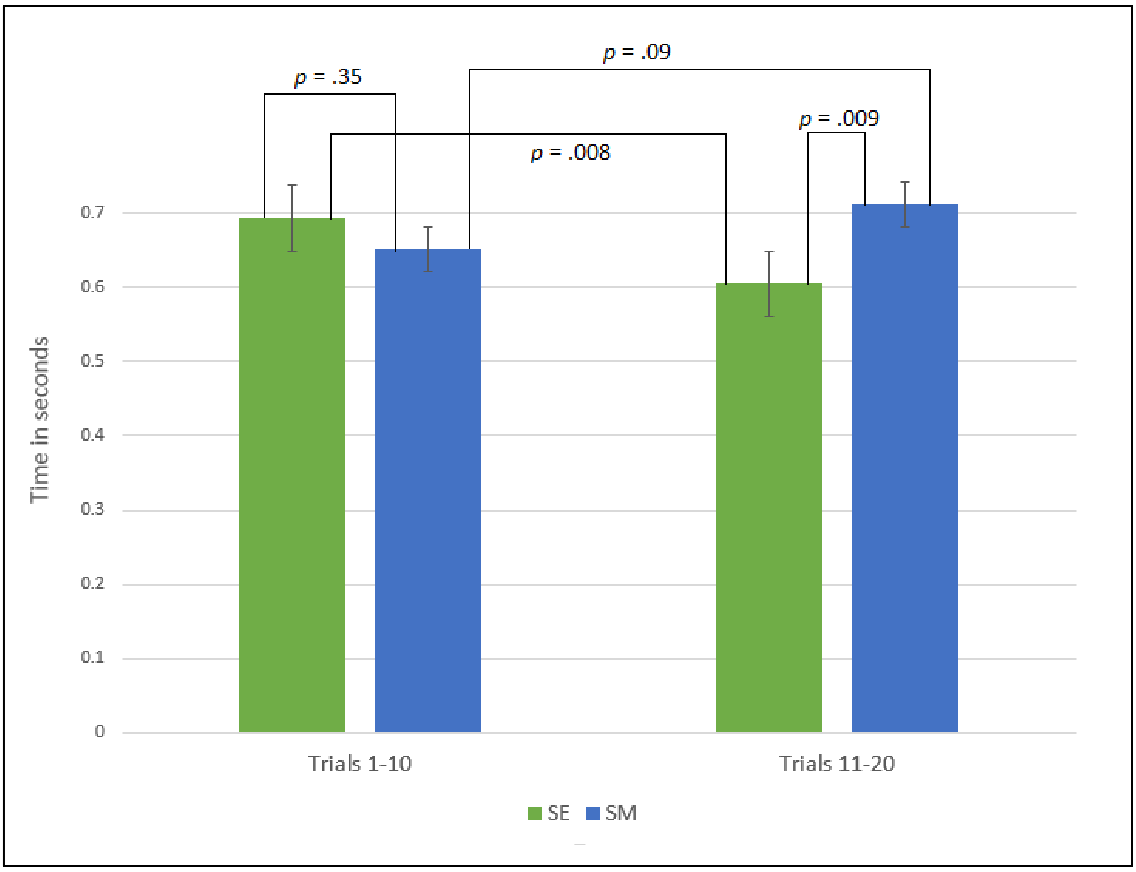


Figure 4. Average Saccadic Response Times for Both Conditions on Trials 1-10 and Trials 11-20. Between conditions there was no difference in response times for trials 1-10, but there was a significant difference for trials 11-20, implicating implicit contingency learning. Within conditions, there was a significant difference in saccadic response times between trials 1-10 and trials 11-20 for only the *SE* condition.

In order to corroborate the finding that infants were sensitive to the different social responses (engaging vs. disengaging), a univariate ANOVA (independent variable: Condition) was conducted on the number of non-trigger trials. The analysis yielded a main effect of Condition ($F(1,156) = 22.375$, $p < .001$, ŋp2 = .125) with infants on average triggering animations on 18.16 out of 20 trials in the SE condition and 17.64 out of 20 in the SM condition.

Behavioural Responses

To assess behavioural responses, it was determined if infants' behaviour was congruent or incongruent with the actor's triggered response. As a consequence of recording errors, the behavioural data from six infants (2 x 6m, 3 X 9m & 1 x 12m) was lost. Preliminary analysis of the remaining data (SE: n = 83; SM: n = 73) revealed no effects of gender, so data were collapsed for further analyses (See Table 3 for details of behavioural responses). As data were highly skewed, a log transform was conducted prior to performing data analyses.

A 3 (Age) x 2 (Condition) x 2 (Response Type; Congruent, Incongruent) univariate ANOVA conducted on percentage of responses revealed a main effect of Condition ($F(1,300) = 18.869$, $p < .001$, $\eta_p^2 = .059$) and Response Type ($F(1,300) = 91.239$, $p < .001$, $\eta_p^2 = .233$), a significant Age x Condition interaction ($F(2,300) = 10.579$, $p < .001$, $\eta_p^2 = .066$) and a Condition x Response Type interaction ($F(2,300) = 11.574$, $p < .001$, $\eta_p^2 = .037$). Inspection of means shows that Congruent responses (M = 16.00%) were observed more frequently than Incongruent responses (M =10.21%) and that the infants were more likely to respond in the *SE* condition (M = 15.47%) relative to the *SM* condition (M = 10.27%). In terms of age-related differences, post-hoc comparisons found that only 9-month-olds (M = 15.12%, p = .036) responded more frequently relative to 6-month-olds (M = 10.40%).

To explore the interactions, separate univariate ANOVAs were conducted for the *SE* and *SM* condition, which yielded age-related differences in the *SE* condition only ($F(2,167) = 6.399$, $p = .002$, $\eta_p^2 = .071$). Post hoc comparisons found that 6-month olds were less likely to respond (M = 8.81%) relative to both 9-month-olds (M = 20.64%; $p = .001$) and 12-month-olds (M = 16.51%; $p < .023$).

Table 3

Mean Percentages of Response Types (SDs in parentheses)

Condition	*Age (in months)*	*Congruent*	*Incongruent*	*Ambiguous*	*Total*
SE	6 (*N* = 29)	10.37 (16.04)	7.25 (9.56)	13.48 (16.55)	31.10 (13.06)
	9 (*N* = 30)	25.04 (21.76)	16.23 (14.07)	11.59 (14.12)	52.86 (20.88)
	12 (*N* = 30)	20.17 (21.77)	13.85 (18.63)	6.42 (6.79)	40.44 (26.28)
	Total (*N* = 89)	18.52 (20.78)	12.48 (14.96)	10.50 (13.65)	41.46 (25.13)
SM	6 (*N* = 24)	11.92 (13.16)	6.15 (8.20)	10.82 (16.85)	28.89 (16.32)
	9 (*N* = 24)	11.69 (17.45)	4.00 (6.99)	8.99 (10.55)	24.68 (19.65)
	12 (*N* = 25)	12.93 (14.45)	6.66 (12.07)	8.32 (7.39)	27.191 (23.09)
	Total (*N* = 73)	12.18 (15.28)	5.60 (9.39)	10.38 (11.71)	27.16 (20.01)
Total	(*N* = 162)	15.89 (18.99)	9.90 (13.47)	10.38 (12.88)	36.17 (24.20)

Distribution of Performance and HR Comparison. Having tested a large sample of typically developing infants in a novel research paradigm provided the opportunity to establish ranges for typical behaviour. To assess behaviour of individual infant siblings z-normalized scores and distributions were produced for key measures. Having constructed z-normalized distributions, it was notable that different measures produced different distribution shapes; normal and skewed. A normal distribution indicates that a behaviour varies naturally within the population. By contrast, a skewed distribution shows that a behaviour is relatively consistent within a population. Following previous research (Kelly et al., 2011) individual infants were deemed to be of interest if their behaviour fell +/- 1.5 SDs from the sample mean. Fisher's Exact Tests were conducted for each of the measures to explore the frequency of deviant z-scores in the preliminary infant sibling data relative to the TD sample.

Skewed Distributions.

Incongruent Responses. The distribution of incongruent responses is heavily skewed (See Figure 5a), with infants consistently displaying a low frequency of incongruent responses. Inspection of the z-scores shows that 2 out of 11 infant siblings (18.2 %) produced unusually high frequencies of incongruent responses. By contrast only 8 out of 145 TD infants (5.5%) displayed comparable behaviour. A Fisher's Exact Test found that Group (TD vs. infant siblings) was not significantly associated with a deviant negative z-score (p = .149). Incongruent responses might be a measure of interest for future research, but statistical significance will have to be investigated in a larger sample.

Eye Triggers. The distribution of eye triggers shows a clear skew (See Figure 5b) with infants highly likely to initially fixate the eye area. Inspection of infant siblings' z-scores shows that 3 out of 11 infant siblings (27.3%) and 13 out of 151 TD infants (8.6%) displayed deviant behaviour. A Fisher's Exact Test revealed that Group was not significantly associated with a deviant negative z-score (p = .080). Decreased eye triggers might be a measure of interest for future research, but statistical significance will have to be investigated in a larger sample.

Normal Distributions.

Eye Region Dwell Time. Dwell time on the eye region is normally distributed (See Figure 5c), indicating that this behaviour naturally varies within the population. Within this normal distribution, infant sibling z-scores are all located in the left side of the distribution with 4 out of 11 infants (36.4%) showing a negative z-score larger than 1.5. Conversely, only 7 out of 151 TD infants (4.64%) displayed comparable behaviour. A Fisher's Exact Test revealed that Group was significantly associated with a deviant negative z-score (p = .003). A relatively low total dwell time on the eye region seems to be characteristic of infant siblings of interest. Eye region dwell time when viewing interactive faces should be considered a measure of interest for future research.

Due to the small infant sibling sample, these results are relatively provisional. Although not all Fisher's Exact Tests have reached significance (yet), heightened rates of occurrences were observed in the infant sibling sample comparable to what should be expected based on what previous research tells us about the percentage of infant siblings that will eventually receive a diagnosis (~20%, e.g. Ozonoff et al., 2011b).

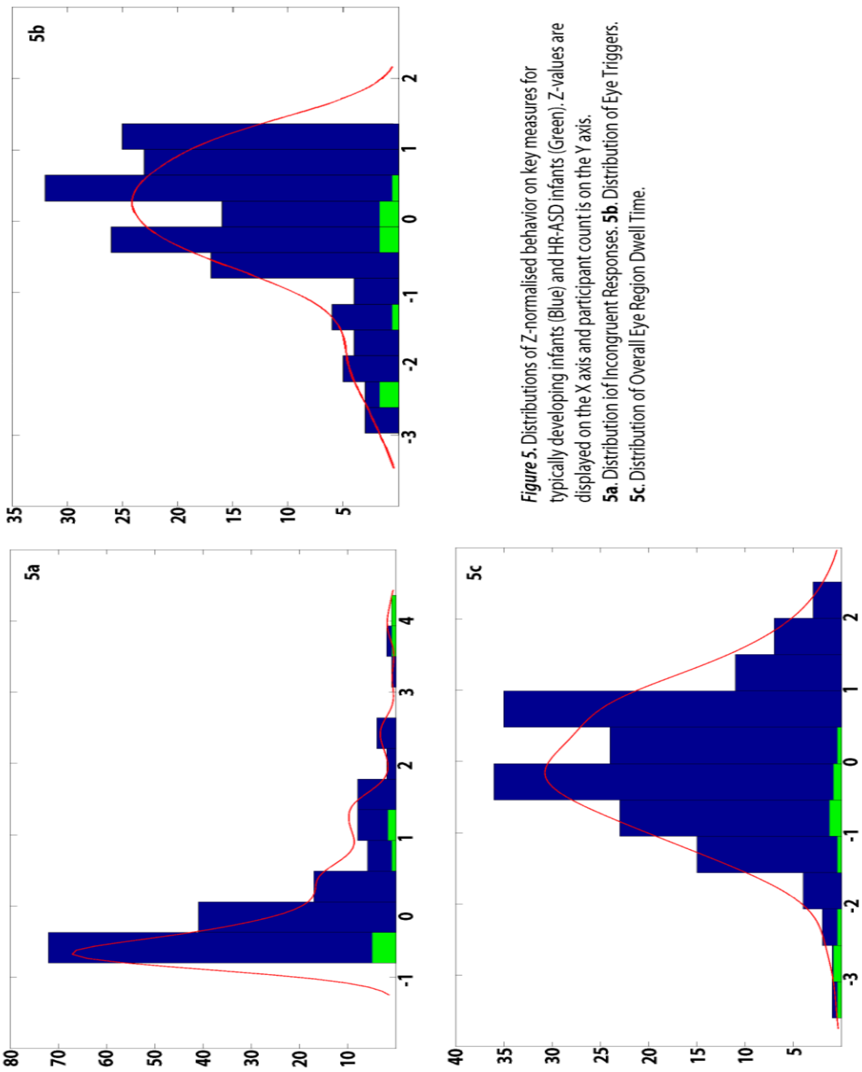


Figure 5. Distributions of Z-normalized Behaviour on Key Measures for Typically Developing Infants (Blue) and Infant Siblings (Green). Z-values are displayed on the X axis and participant count on the Y axis. **5a.** Distribution of Incongruent Responses. **5b.** Distribution of Eye Triggers. **5c.** Distribution of Overall Dwell Time on Eyes.

Discussion

Previous studies exploring face scanning in infancy have employed *non-interactive* stimuli to answer questions about an inherently *interactive* process. For the current study, a novel eye-tracking method, a gaze-contingency paradigm, was developed which allowed for the simulation of the social context in which face scanning typically occurs in day-to-day life by presenting infants with interactive faces.

Dwell Time in a Gaze-contingency Paradigm

The findings demonstrate that regardless of condition infants spent more time fixating the eye area relative to the mouth area, which fits with previous research (e.g. Haith et al., 1977). The mouth area was fixated more in the *SE* condition, which is accounted for by infants' tendency to look directly at the mouth once a smile was initiated. In accordance with previous studies (e.g. Lewkowicz & Hansen-Tift, 2011), the current findings demonstrate that dwell time on eyes declined between 6 and 12-months. Thus, these previously established findings were supported within a gaze-contingency paradigm. Additionally, there was a relatively large percentage of fixations on other face areas compared to the mouth area, which is likely a consequence of the task's interactivity. Scanning a static image of an isolated face in a lab setting could encourage repetition of a triangular pattern of fixations (e.g., right eye – left eye – nose) while disregarding other face areas. In an interactive paradigm, dynamic movement attracts a broader distribution of fixation patterns that is likely to be more representative of natural face-to-face interactions.

Contingency Learning

Within social interaction, contingent responses are highly important for infants' development of social understanding (Markova & Legerstee, 2006) and from as young as 2 months, infants are sensitive to contingencies (e.g. Soussignan et al., 2006). Previous studies have overlooked the contingency of social interaction, whereas the gaze-contingent stimuli provided this critical element. Consequently, it was hypothesized that infants would explicitly learn the contingency of the task and that their subsequent initial fixations would fall in the area of the face that resulted in triggering a socially engaging response. However, the current study found that infants were more likely to initially fixate the eye area, regardless of condition. More specifically, infants in the *SM* condition did not show evidence of learning that fixating the mouth would produce a socially engaging response. In other words, even when fixating the eye area triggered a socially disengaging response, infants persisted in making eye contact. This replicates previous research demonstrating a strong preference for eye contact (e.g. Di Giorgio et al., 2013). Additionally, this supports the view that infants are deploying a well-rehearsed strategy of engaging in eye contact in order to engage in social interaction and that 20 trials provided insufficient training time to completely deter infants from this behaviour.

Interestingly, infants did show evidence of *implicit* contingency learning, which was inferred by contrasting saccadic response time from trials 1-10 and trials 11-20. Across trials saccadic response times were *decreasing* in the SE condition (i.e. engagement), but *increasing* in the SM condition (i.e., disengagement). Thus, while 20 trials were not enough to demonstrate explicit contingency learning, the gaze-contingent task was capable of detecting infants' sensitivity to engaging and disengaging actors whilst scanning their faces, which was corroborated by the difference in non-trigger trials between conditions.

Reciprocity

Previous studies exclusively focussed on infants' eye movements deployed during face scanning. As the interactive gaze-contingency paradigm allowed for the simulation of a social interaction, it was possible to study the additional measure of infants' reciprocity. Infants clearly showed a difference in behaviour towards socially engaging and socially disengaging actors. Infants who received a socially engaging response provided a higher frequency of positive responses, suggesting that they enjoyed interacting with the on-screen actor. Conversely, infants who repeatedly triggered a socially disengaging response seemed to withdraw from the task, which is further highlighted by the fact that 16 infants had to be excluded from this condition due to complete disengagement. Infants who did respond to a socially disengaging actor, displayed clear disagreement. Although the overall response rate across conditions appears low (36.17%), it is important to point out that infants were interacting with unfamiliar faces. Relative to previous research on stranger sociability in infancy (e.g. Corter, 1973), the reported response rates in this study are notably high. The interactive task encouraged infants' active engagement and facilitated responsiveness and sociability (see Ross & Goldman, 1977).

Other Applications

The current findings demonstrate that the implementation of gaze-contingent stimuli allows for a more nuanced investigation of face scanning. Measures of contingency and reciprocity were collected, and infants appeared sensitive to social nuances observable in both their eye-tracking (saccadic response times) and behavioural data. As an additional strength, the task could be employed to explore early signs of atypical social development due to a more naturalistic and socially demanding experience. In addition to dwell time, the task can provide measures of contingency learning and reciprocity, skills that are reportedly less developed in children with autism spectrum disorder (e.g. Constantino, Przybeck, Friesen & Todd, 2000). To preliminarily investigate this application, this study descriptively compared a small sample of infant siblings of children with ASD to z-normalized ranges of typical behaviour. Decreased dwell time on eyes seemed to be associated with infant sibling status, which corresponds with earlier findings (Merin et al. 2007). In light of previous studies (e.g. Lewkowicz & Hansen-Tift, 2011), it is expected that older infants redirect their focus to the eye area of a face. Given that the majority of the infant siblings were 12 months old, the current findings seem to indicate deviant behaviour. Additionally, a high frequency of incongruent responses and a lower frequency of eye triggers could be potential measures of interest. A larger infant sibling sample is required to further probe these findings and to assess whether these measures are indeed associated with infant sibling status. Although preliminary, these findings demonstrate that even in a sample with 11 infant siblings, a gaze-contingency paradigm is capable of highlighting infant siblings of interest and suggests potential utility for contributing to early detection.

Conclusion

No studies to date had employed a gaze-contingency paradigm in face scanning research, whereas the interactive nature of the paradigm lends itself perfectly for research in the area of social interaction. The increased ecological validity of the interactive stimuli allowed for expansion on earlier findings on face scanning by providing measures of contingency learning and reciprocity in addition to a more naturalistic dwell time analysis. Infants clearly showed sensitivity to differences in engagement from actors, which was visible in both saccades and their overt behavioural responses. This study preliminarily demonstrated the potential application of a gaze-contingency paradigm in atypical populations, but further studies are required to corroborate these findings. One limitation to this study was the relatively low power in the Condition x Response interaction for behavioural responses. Accordingly, future studies will require larger sample sizes to address this shortcoming. It is proposed that when implemented correctly, interactive gaze-contingent stimuli will allow for more meaningful conclusions in eye-tracking studies in both typical and atypical developmental populations and will make important contributions to advancements in the field of developmental psychology.

This chapter demonstrated how a gaze-contingency paradigm can be implemented effectively to study responses to social engagement and disengagement during face scanning in an infant sample. The interactive nature of the gaze-contingency paradigm allows for the study of numerous social processes. In the next chapter, I will build on the current study by introducing novel interactive stimuli, and by including a substantially larger sample of infant siblings of children with ASD. In the forthcoming study, I firstly intend to advance the knowledge on early socio-communicative development further. Secondly, I aim to contribute to the literature on endophenotypic markers for ASD.

Chapter 4

Eye Movements and Behavioural Responses to Gaze-Contingent Expressive Faces in Typically Developing Infants and Infant Siblings

Introduction

The previous chapter introduced the gaze-contingency method and demonstrated the efficacy of the paradigm in a large sample of typically developing (TD) infants. The paradigm seems to offer a more socially demanding and interactive experience compared to stimuli used in previous research by more closely approximating a real-life interaction. The findings showed that infants display behavioural responses induced by the interactive nature of the paradigm and that they are sensitive to the difference in socially engaging and socially disengaging reactions from the on-screen actors. Additionally, analysis of a small sample of infants at elevated familial risk for an autism spectrum disorder diagnosis suggested that gaze contingent stimuli have the potential to detect early social deviancies. The current chapter will extend these findings by including novel interactive stimuli. More specifically, the on-screen actors will respond with one of the six basic emotional expressions (happiness, anger, surprise, fear, disgust and sadness; Ekman, 1973), provided that infants engage in eye contact. Furthermore, this chapter will include a substantially larger sample of infant siblings to further examine the findings on the ability of the gaze-contingent method to detect early social deviancies indicative of atypical social development.

Research with Infant Siblings

A growing body of research has focused on the prospective study of the emergence of autism spectrum disorder (ASD) by studying infant siblings of children with an ASD diagnosis (see Jones et al., 2014 and Szatmari et al., 2016 for reviews). Infant siblings are at elevated familial risk; ASD prevalence within this group is 20% compared to 1.5% in the general population (Ozonoff, 2011; Szatmari et al., 2016). Furthermore, a considerable proportion of non-diagnosed infant siblings present with other developmental issues (Charman et al., 2017; Piven et al., 2018). Uncovering early behavioural, and potentially symptomatic, manifestations of ASD, could lead to earlier diagnosis (Koegel et al., 2014; Zwaigenbaum et al., 2013) and greater opportunity for appropriate interventions that can significantly improve prognosis (Dawson et al., 2010; Dawson et al., 2012; Fernell et al., 2013; MacDonald et al., 2014). Nevertheless, ASD is currently not reliably diagnosed before 24 months of age (Steiner et al., 2011) and the median age of diagnosis in the UK is 55 months (Brett et al., 2016). Moreover, a very recent study shows that the majority of children is not diagnosed until after entering primary school (Hosozawa et al., 2020). With only 1 in 5 infant siblings eventually receiving an ASD diagnosis, establishing a reliable first-year marker with predictive clinical value is pivotal to enable targeted intervention. Recent studies have demonstrated moderate predictive success at 14 (Bussu et al., 2018) and 18 months (Chawarska et al., 2014). Yet, a reliable first-year marker remains elusive.

Novel Methodologies

In the present chapter, it is argued that in order to reliably identify early manifestations of ASD, the appropriateness of the research methods employed in studies with infant siblings needs to be carefully considered. Fundamentally, ASD is a social-communication disorder (APA, 2013; Schulz, 2005); therefore, in order to capture subtle early deviancies in behaviour, researchers must develop methods that are sufficiently socially demanding and realistically interactive. Similarly, Bussu et al. (2018) argue that the lack of reliable predictors could be due to the inability of current methods to capture ASD-related manifestations of social skills at an early age. Consequently, the current study advocates the utilisation of gaze-contingent eye-tracking paradigms as a novel interactive method to study infant sibling behaviour. In gaze-contingency paradigms, responses from a stimulus are contingent on participants' eye movements, enabling participants to 'interact' with stimuli. Recent studies demonstrated the utility of gaze-contingency paradigms with both typical and atypical populations (Deligianni et al., 2011; Miyazaki et al., 2014; Vernetti et al., 2018; Wang et al., 2012, Wilms et al., 2010).

Chapter 1 demonstrated the successful application of a gaze-contingency paradigm to study face scanning in TD infants and infant siblings (Keemink et al., 2019). In this paradigm infants could 'interact' with on-screen actors by fixating pre-specified regions of the actors' face. Specifically, fixating the eyes or mouth triggered a socio-communicative response from the actor. Gaze-contingency paradigms are particularly suitable to study socio-communicative behaviour as they allow for the simulation of a realistic social interaction whilst retaining empirical rigour. The paradigm was enhanced by video-recording participants during the 'interactions' to obtain a measure of infant socio-communicative responsiveness. The findings of Chapter 1 demonstrated that infants are sensitive to differences in engagement from actors, which was visible in their eye movements and their overt behavioural responses. Additionally, preliminary findings from our small infant sibling sample suggested deviant behavioural responsiveness and atypical dwell time as potential early markers of ASD. The current study aims to build on these findings by extending the paradigm with novel, emotionally expressive stimuli and by including a larger sample of infant siblings.

Expressive Stimuli

Emotional expressions are inherent to human interactions and essential socio-communicative signals for survival (Bannerman et al., 2009). It is therefore pivotal for social success that infants develop the ability to discriminate, categorize, and comprehend a multitude of different emotions (Izard et al., 2001). Studying how infants process social-communicative expressions is particularly relevant in the context of infant sibling research, as older children with ASD show difficulties in emotion processing (Dapretto et al., 2006; Begeer et al., 2008; Rosset et al., 2007). To date, emotion processing in infant siblings has not been studied using interactive faces, although several studies suggest it could be a relevant endophenotypic marker (Blasi et al., 2015; Fox, Wagner, Shrock, Tager-Flusberg & Nelson, 2013; Mattson et al., 2013; McCleery, Allman, Carver & Dobkins, 2007; Wagner et al., 2016). Studies with TD infants suggest that infants as young as 36 hours show some evidence of emotion discrimination (Addabo et al. , 2018; Farroni et al., 2007), which becomes more distinguished over the first few months (Barrera & Maurer, 1981; Nelson & Dolgin, 1985; Schwartz et al., 1985). Emotion categorization develops slightly later (Caron et al., 1988; Cong et al., 2018; Kotsoni et al., 2001; Ludemann, 1991), and some studies suggest that TD infants show expression-specific eye movements, in particular to threat-related expressions (Gredebäck et al., 2011; Hunnius et al., 2011). Discrimination and categorisation provide evidence that infants can perceive the *perceptual* difference between expressions. However, the mastery of these skills does not provide information about infants' ability to comprehend the *conceptual* differences between expressions. Arguably, discrimination and categorisation can follow from the ability to decode lower-level visual properties, whereas emotion comprehension, understanding the social meaning that the different expressions convey, relies on higher-order processes. Interestingly, very few studies have explicitly addressed emotion comprehension in TD infants (Phillips et al., 1990; Soussignan et al., 2017). Several studies conclude an attentional bias towards fearful faces (see review Leppänen & Nelson, 2012), suggesting a robust understanding of its valence, although evidence is mixed. Other studies reason that infants are capable of understanding the valence of emotions, but evidence is either theoretical (Tronick, 1989) or limited to mothers' faces (Sorce et al., 1985; Sroufe, 1979). Emotion comprehension seems to follow a more protracted course, but further study with TD infants is needed to unravel the details of its development. It is currently also unclear if these behaviours develop similarly in infant siblings and therefore the current study aims to probe expression comprehension in TD infants, as well as examining if and how these processes deviate in infant siblings by measuring responses to gaze-contingent face stimuli portraying the six basic emotional expressions (happiness, anger, surprise, fear, disgust and sadness; Ekman, 1973).

The Current Study

Although eye tracking permits the study of cognitive processes in preverbal infants in a non-invasive manner, it is questionable as to whether eye movements alone are most suited to reveal meaningful socio-communicative differences between clinical groups and subgroups. Several eye-tracking studies report differences in fixation patterns (Chawarska et al., 2013; Guiraud et al., 2012; Merin et al., 2007). However, these are not always reliably linked to ASD diagnosis (Young et al., 2009). Moreover, a review by Falck-Ytter et al. (2013) highlights that although eye tracking can be a valuable method in autism research, integration with more naturalistic measures is needed. Interestingly, the findings from Chapter 1 (Keemink et al., 2019) suggest that deviant behavioural responsiveness could be a measure of interest. The current study will investigate this further in a larger infant sibling sample by combining eye-tracking and natural behavioural responses. In contrast to previous research, the interactive gaze-contingency paradigm enables the incorporation of a measure of infant responsiveness, which will be video-recorded, allowing for the investigation of early socio-communicative development in a more meaningful way. Additionally, the present study will adopt a novel analysis approach by exploring differences between TD infants and infant siblings not only at the group level, but also by investigating individual performance (see Keemink et al., 2019). It is proposed that infant siblings cannot be categorized as a separate group, as the majority of these infants will develop typically (Ozonoff et al., 2011b). Meaningful deviant behaviour could therefore be masked at the group level.

Existing research (Di Giorgio et al., 2013; Keemink et al., 2019) led to the hypothesis that all infants would engage in eye contact with the interactive face stimuli and therefore trigger the expressive responses. In TD infants, it was expected that moderate to high rates of responsiveness towards the interactive stimuli would be observed (Keemink et al. 2019). In line with previous work, subtle differences were expected between TD and infant sibling participants, characterized by behavioural responses (Fox et al., 2013; Keemink et al., 2019) and by eye movements (Rosset et al., 2007). Lastly, it was reasoned that if infants deployed emotion-specific eye-movements, this would support conclusions about emotion categorisation, and if infants demonstrated emotion-specific behavioural responses, basic expression comprehension could be inferred.

Methods

This study was approved by the Ethics Committee of the University of Kent (Ethics ID: 201815168322884850) and the NHS Health Research Authority (IRAS: 239237). All parents signed informed consent for their infant. Data were stored and treated anonymously.

Participants

Typically developing infants were recruited through the Kent Child Development Unit database including families interested in participating in research. Infants were considered TD if they had not been born prematurely (<6 weeks) and had no family history of autism spectrum disorder. The final TD sample comprised 122 infants (64 male, 58 female) consisting of 6-, 9- and 12-month-olds. A further 5 infants (2 x 6 months, 2 x 9 months, 1 x 12 months) were excluded from analysis due to fussiness. Infant siblings were recruited via The Kent Autistic Trust and Community Child Health, East Kent Hospitals University NHS Foundation Trust. Infants were included if they had at least one older sibling with an ASD diagnosis. All autistic siblings had received a formal diagnosis established by a clinical psychologist. The final infant sibling sample comprised 31 infants (17 male, 14 female) consisting of 6, 9-, and 12-month-olds. See Table 1 for detailed participant characteristics.

The Gaze-Contingent Task

All infants viewed 18 video-recorded, neutral-looking actors, who would produce expressions representing one of the six basic emotions (happiness, sadness, surprise, disgust, fear and anger) at the moment the infant engaged in eye contact with the actor. The expression produced by the actors was contingent on the infant's first fixation in the eye region (see Figure 1). All six expressions were represented three times and were presented in a random order. If an infant did not fixate the eye region within the trial length, the face would not animate and remain looking neutral. All infants included in the final sample completed a minimum of 15 trials. The trial length of trials where infants did fixate the eye area was 3 seconds (length of the video) plus the time it took infants to fixate the eye area. A trial would be a maximum of five seconds long.

Table 1

Participant Characteristics per Age and Group

	Age in Months	*N*	*Mean Age in Days (SD)*	*Age Range*	*Gender (M/F)*
TD	6	46	191.1 (9.4)	176 – 194	26/20
	9	39	281.3 (11.2)	265 - 290	18/21
	12	37	367 (12.5)	357 - 378	19/18
	Total	122			64/58
HR-ASD	6	6	185 (7.2)	175 - 193	5/1
	9	12	275.7 (7.5)	263 - 282	6/6
	12	13	369.1 (6.8)	364 - 381	6/7
	Total	31			17/14
Total		153			80/73

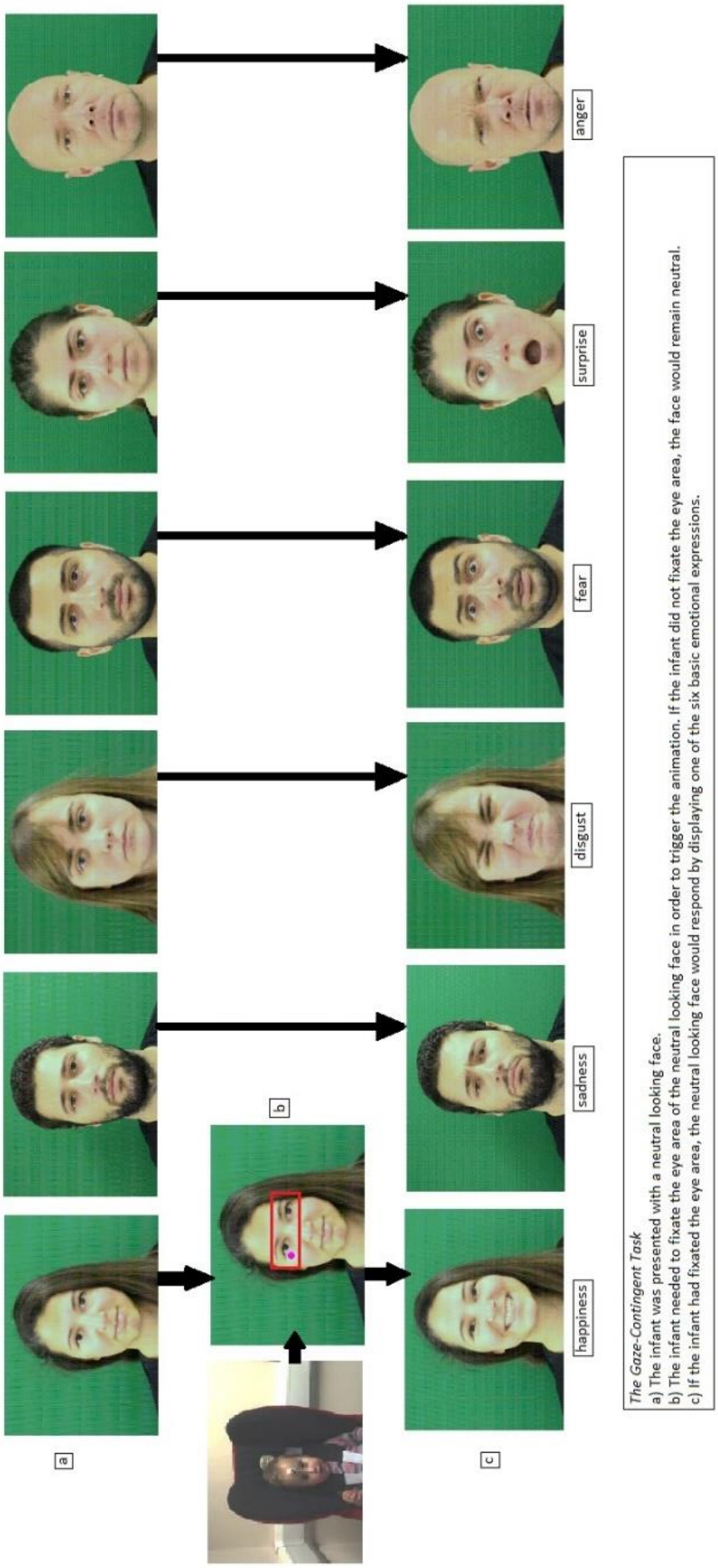


Figure 1. The Gaze-Contingent Task

Stimuli

Stimuli consisted of 18 colour videos of 18 neutral-looking adults (9 females, 9 males) visible from the shoulders upward standing in front of a green screen (See Figure 2). All stimuli were of Caucasian origin, with the exception of one mixed race stimulus. Race did not affect infant responses. All images subtended a size of 24.77 degrees x 18.25 degrees in visual angle and were presented on a 20-inch monitor with a resolution of 1024 by 768 pixels. Discrete gaze-contingent ‘invisible boundaries’ for the eye region were defined individually for each face. All eye regions measured 8.3 x 3.4 degrees.

Figure 2. An Example of a Neutral-Looking Stimulus

Equipment

Equipment details were identical to those of Chapter 3 (See page 64).

Procedure

The procedure of this study was identical to the procedure described in Chapter 3 (See page 64).

Behavioral Coding

Infants' behavioral responses were video recorded with a webcam. Eye-movement data were time-locked with behavioral data to ensure that infants' behavior occurred in *response* to the triggered animation. Subsequently, recordings were analyzed frame-by-frame to code the infants' responses. Responses could be categorized as approach (e.g. smiling), withdrawal (e.g. averting gaze), ambiguous (e.g. arbitrary head movements), or non-response (no change in facial expression/behavior). Responses were also coded for imitation of the triggered expression. Subsequently, behavioural response data was compared to the eye-tracking data to determine the frequency of imitation. All recordings were coded by a researcher and a blind coder. Inter-coder reliability was high (r =.89, p <.001).

Eye Movements

A velocity-based algorithm was used to identify saccades that has been successfully implemented in several recently published papers (Keemink et al., 2019; Kelly et al., 2019; Prunty et al., 2020). Data was smoothed by applying a 4-sample rolling window that returned a median average. Angular speed was computed based on four samples. Velocity values greater than 1000°/sec were judged to be impossible and removed from analysis. A velocity threshold of 40°/sec was set, with samples falling below this value identified as potential fixation samples. Time and distance between 2 potential fixations were calculated. If inter-fixation values were <20ms and <.03° then fixations were merged. All fixations <100ms were removed. Following Holmqvist, Nyström and Mulvey (2012), precision values were calculated as the root mean square (RMS) of sample-to-sample distances within computed fixations. Precision was calculated separately for each age group and results were as follows: 6 months = 0.71° (*SD* = 0.12°), 9 months = 0.64° (*SD* = 0.08°) and 12 months = 0.61° (*SD* = 0.09°).

In order to identify fixations directed to key face features, Areas of Interest (AOIs) were constructed individually for each face stimulus. The size of AOI regions was identical across all faces (Eyes = 8.3° x 3.4°; Nose = 3.6° x 2.4°; Mouth = 6.2° x 3.4°) but AOI locations differed spatially as dictated by the physiognomic proportions of individual faces.

Results

Power Analysis

When data collection had taken place for a significant amount of time, post-hoc power analyses were conducted to evaluate whether the gathered sample had sufficient power. With a total sample of 122 TD infants and 31 infant siblings, all main and interaction effects adhere to a power of at least .80.

Analysis Plan

First, the results will describe eye movement analyses exploring differences in overall Dwell Time and in looking time towards the distinct AOIs. Subsequently, infants' behavioural responses will be analysed investigating differences in overall Responsiveness, Imitation and Smiling. The within-subject variables are Expression (six levels - happiness, surprise, dear, disgust, anger, sadness) and AOI (three levels – eyes, mouth, nose). The between-subject variables are Age (three levels - 6-, 9- and 12-month-olds) and Group (two levels – typically developing infants and infant siblings). Age has been included to demonstrate consistency of results across ages, no age differences were found. Analyses revealed no effect of participant gender, so this factor was excluded.

The analyses will firstly be discussed at group level using repeated measures ANOVAs. However, since only 1 out of 5 infant siblings will receive an ASD diagnosis (Ozonoff et al., 2011b), it is argued that group-level analyses might not be sufficient. This may result in meaningful individual differences remaining unnoticed. Similar to Keemink et al. (2019), the performance of individual infant siblings relative to TD behavior will therefore additionally be discussed by investigating the frequency of deviant behavioral responses for each measure. Infants were deemed of interest if their behavior fell +/- 1.5 standard deviations from the sample mean (cf. Kelly et al., 2011). Fisher's exact tests explored the difference in frequency of deviant z-scores between TD infants and infant siblings.

Eye Movement Analyses – Group Level

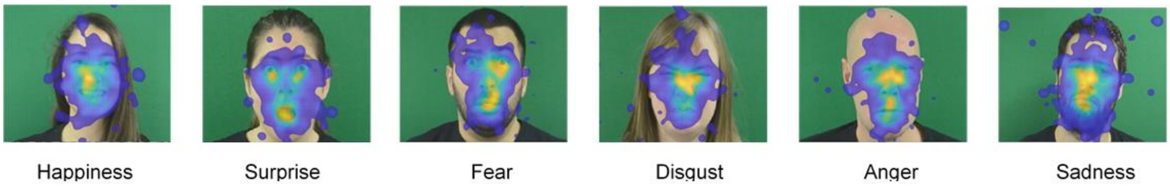
Overall Dwell Time. The dependent variable for these analyses was total looking time in seconds. A 6 x 3 x 2 repeated measures ANOVA yielded a significant main effect of Expression, $F(5, 735) = 4.949$, $p < .001$, $\eta_p^2 = .033$. Post-hoc analyses revealed that infants looked significantly longer at surprised expressions compared to happy ($p < .001$), fearful ($p = .003$), disgusted ($p < .001$), angry ($p = .035$) and sad expressions ($p < .001$) (See Table 2 for means) across all ages and regardless of group status.

AOIs. The dependent variable for these analyses was percentage of total looking time. A 3 x 6 x 3 x 2 repeated measures ANOVA revealed a significant main effect of AOI, $F(2, 294) = 58.331$, $p < .001$, $\eta_p^2 = .284$. Post-hoc inspection of means confirmed that across expressions eyes were fixated more (31.9%) than nose (13.8%, $p < .001$) and mouth (15.9%, $p < .001$) by infants of all ages and regardless of group status. Additionally, a significant Expression x AOI interaction was found $F(10, 1470) = 5.592$, $p < .001$, $\eta_p^2 = .037$, with infants distributing their fixations to AOIs differently per expression (see Table 3). Figure 3 provides a visual representation of the interaction effect.

Table 2

Mean Looking Time (in seconds) for Each Expression

Expression	*Mean (SE)*
Happy	3.830 (.093)
Surprise	4.259 (.073)
Fear	3.914 (.098)
Disgust	3.869 (.087)
Anger	4.056 (.075)
Sadness	3.874 (.083)



Areas marked in yellow signify which part of the face infants fixated most. The figure shows that infants' fixations were distributed differently per expression.

Figure 3. Visual representation of the Expression X AOI interaction.

Eye Movement Analyses – Individual Performance

Dwell Time & AOI. For overall Dwell Time and AOIs, z-scores were computed and the frequency of deviant z-scores was examined for TD infants and infant siblings. Fisher exact tests revealed no significant differences in frequency.

Infant siblings and TD infants showed no differences in their eye movements whilst watching expressive stimuli in the gaze-contingent paradigm.

Behavioural analyses – Group Level

Overall Responsiveness. Descriptive statistics demonstrated that on average infants showed a behavioral response on 58% of trials. A 6 x 3 x 2 repeated measures ANOVA on percentage of trials yielded a significant main effect of Expression, $F(5, 735) = 3.301$, $p = .006$, $\eta_p^2 = .022$. Infants in all age groups responded more towards happiness relative to surprise ($p = .001$), fear ($p = .009$) and sadness ($p = .003$), and more toward disgusted expressions compared to surprised expressions ($p = 0.12$).

Imitation. Descriptive statistics demonstrated that on average infants showed imitation on 5.56% of trials. A 6 x 3 x 2 repeated measures ANOVA conducted on percentage of trials revealed a significant main effect of Expression, $F(1, 147) = 27.734$, $p < .001$, $\eta_p^2 = .159$. Infants in all age groups imitated happiness significantly more than other expressions (all $p < .001$). Additionally, a significant main effect of Group, $F(1, 147) = 7.262$, $p = .008$, $\eta_p^2 = .047$ demonstrated that infant siblings exhibited less imitation (3.04%) than TD infants (6.21%).

Smiling. On average infants smiled on 21.24% of trials. A 6 x 3 x 2 repeated measures ANOVA conducted on percentage of trials revealed a significant main effect of Group, $F(1, 147) = 4.10$, $p = .042$, $\eta_p^2 = .028$. Infant siblings showed less smiling (12.58%) than TD infants (23.37%).

Behavioural Analyses – Individual Performance

Z-scores were computed for overall responsiveness, and the frequency of deviant z-scores was examined. For imitation and smiling rates, the restricted range of values (resulting in no normalised values falling below -1.5 SDs) required an alternative approach. For these measures, the frequency of absence and presence of the behaviour was examined instead.

Responsiveness. Inspection of z-scores revealed that eight out of 31 infant siblings (25.81%) produced unusually low rates of responsiveness relative to only 12 out of 122 TD infants (9.84%). A Fisher's Exact Test yielded a significant difference in frequency, $p = .032$.

Imitation. Inspection of z-scores revealed that 19 out of 31 infant siblings (61.29%) did not show any evidence of imitation relative to 43 out of 122 TD infants (35.25%). A Fisher's Exact Test yielded a significant difference in frequency, $p = .013$.

Smiling. Inspection of z-scores revealed that 17 out of 31 infant siblings (54.84%) did not exhibit any smiling. Conversely, 41 out of 122 TD infants (33.61%) showed similar behavior. A Fisher's Exact Test yielded a significant difference in frequency, $p = .038$.

Table 3

Mean Proportion of Looking Time per AOI for Each Expression

Expression	*AOI*	*Mean (SE)*
Happy	Eyes	.307 (.020)
	Nose	.144 (.014)
	Mouth	.159 (.016)
Surprise	Eyes	.285 (.021)
	Nose	.137 (.012)
	Mouth	.227 (.018)
Fear	Eyes	.375 (.023)
	Nose	.100 (.012)
	Mouth	.125 (.015)
Disgust	Eyes	.345 (.022)
	Nose	.132 (.014)
	Mouth	.138 (.015)
Anger	Eyes	.301 (.020)
	Nose	.175 (.015)
	Mouth	.161 (.018)
Sadness	Eyes	.299 (.022)
	Nose	.138 (.014)
	Mouth	.146 (.016)

Discussion

The present study aimed to contribute to the emerging literature on early manifestations of ASD in infant siblings by assessing infants’ eye-movements and behavior in response to gaze-contingent stimuli conveying socio-communicative information. This interactive research paradigm provides a better understanding of how infants, both typically developing and at risk for atypical development, process expressive socio-communicative faces. The presented findings underscore the strengths of the gaze-contingency paradigm as an interactive and socially demanding research method capable of detecting early manifestations of ASD and highlights the additional value of behavioural responses in an eye-tracking task.

Eye-tracking Responses

In line with Keemink et al. (2019), all infants engaged in eye contact and triggered the expressive responses. Additionally, infants employed expression-specific eye movements, indicating that they are capable of perceiving *visual* differences between expressions, and confirming previous studies on emotion categorisation and discrimination (e.g. Hunnius et al., 2011). Eye-movements analyses revealed no meaningful differences between TD infants and infant siblings at both the group and individual level, suggesting that visual exploration of interactive faces in infant siblings is typical and other measures are required to reliably observe early deviancies.

Behavioural Responses

The gaze-contingency paradigm demonstrated that infants do not show expression-appropriate behavioural responses in the first year of life. While eye-movement patterns differ across expressions, infants' typical behavioural response is smiling regardless of group status. With the exception of 'happiness' to which infants readily respond with a smile, infants are not providing behavioural responses that suggest conceptual understanding at this age. Additionally, imitation for expressive faces appears to be rare. Findings indicated that 'happiness' was imitated significantly more than other expressions. However, it important to note that this result is likely to be driven by the high prevalence of smiling in general. In fact, although 'happiness' induced smiling more than other expressions, smiling arbitrarily occurred towards all six expressions. Furthermore, although previous research suggests mimicry of emotional and non-emotional facial actions from 4 months of age (de Klerk et al., 2018; Isomura & Nakano, 2016), these studies only presented infants with simple actions, such as 'mouth opening', and not with full, complex expressions.

It was argued that group-level analyses might not be sufficient to detect symptomatic behaviour in infant siblings, as they cannot be treated a separate group, which was clearly corroborated by the behavioural findings of this study. Whereas differences in imitation and smiling yielded significance at group level, responsiveness did not. However, looking at individual behaviour, the findings revealed that the frequency of deviant behaviour on all three measures is higher in infant siblings relative to TD infants when viewing interactive expressive faces. This cannot be explained by a difference in the amount of triggered expressions, as infant siblings and TD infants triggered expressions equally. These findings converge with studies on parent-infant interaction in infant siblings (Wan, et al., 2012) suggesting reduced social responsiveness in infant siblings and with neuropsychological research on expression processing in children with ASD (Dapretto et al., 2006). Furthermore, the results align with the APA (2013) criteria of ASD, which are characterised by a core social deficit. In addition to demonstrating the need for individual analyses, our behavioural findings compellingly underline the value of video recordings during eye-tracking tasks as a measure of early behavioural differences in infant siblings. The behavioural measures offered an in-depth analysis of the interaction and enabled the detection of subtle socio-communicative differences.

A limitation to this study is the lack of infant sibling follow-up data. Evidently, follow-ups with participants are required to establish the predictive value and specificity of the proposed measures (Piven et al., 2018), for which the first phase has been initiated. Future studies should aim to recruit a larger sample of infant siblings and should include follow-up data. Nevertheless, our method has yielded promising results and this study has provided an important first step in establishing deviancies in behavioural responsiveness.

Implications for Infant Sibling Development

Reduced responsiveness to socio-emotional, interactive stimuli has demonstrable implications for further infant sibling development. The infant is part of a social world, in which responses are contingent upon input. Arguably, diminished responsiveness affects the frequency and ways their social world responds to infants (Leezenbaum et al., 2014). Indeed, studies on parent-infant sibling interaction suggest that parents display less infant-sensitive responses and obtain more directive interaction styles (Wan et al, 2012; Yirmiya et al., 2006). Such interaction styles may in-turn affect the infant, as research with typical populations underscores the importance of contingent parental responsiveness for cognitive and social development (Ainsworth, Bell & Stayton, 1974; Tamis-LeMonda et al., 2014). However, it is complicated to tease apart the order of parental and infant behaviour. Due to the complexities of interaction it remains unclear if parents adjust their communication styles because of their infant's reduced engagement, or if infants' social responsiveness is affected by their parent's alternative communication style. Future longitudinal studies examining how infant sibling and parent interactional behaviours affect each other are required for further understanding of the mechanisms behind this potential developmental trajectory of ASD, which subsequently can inform early intervention.

It is important to acknowledge there may be many different pathways to ASD, which is supported by research (Jones et al., 2014; Landa, Gross, Stuart & Bauman, 2012). Considering the heterogeneity of the disorder, it seems highly unlikely that one behavioural marker will be present in all infants who develop ASD. Nevertheless, the present findings contribute to the literature on early markers by demonstrating that behavioural measures within the gaze-contingency paradigm are capable of detecting early differences.

Conclusion

Despite its potential clinical utility and interactive nature, no studies to date have investigated early socio-communicative deviancies using a gaze-contingency paradigm. The current study demonstrated that video recordings during a gaze-contingent eye-tracking task can detect early deviances in behavioural responsiveness in infant siblings. Additionally, this study contributed to the wider infant literature by confirming that infants perceive *visual* differences between expressions and demonstrating that infants *conceptual* understanding is at its best rudimentary in the first year of life. The results advocate for the implementation of gaze-contingency paradigms within developmental research, as its interactive nature has the potential to study numerous social processes in different populations. These findings hold important implications for early infant sibling development that need to be investigated further in order to provide adequate support as early as possible.

Building on Chapter 3, the present chapter further established the efficacy of the gaze-contingency paradigm and demonstrated its promising ability to detect early social deviancies. The findings suggest that relative to TD infants, infant siblings present with reduced social responsiveness when interacting with gaze-contingent face stimuli. Although the gaze-contingency paradigm was designed to capture the reciprocity and contingency inherent to social interaction, it cannot replace a real face-to-face interaction. Therefore, it remains relevant to examine social responsiveness in infant siblings during a real-life interaction. Furthermore, in order to validate the methods employed in infant sibling research, it is important to examine behaviour across different contexts. The forthcoming chapter will therefore explore how the findings of the current chapter relate to measures of social responsiveness during a live parent-infant interaction.

Chapter 5

A Cross-Context Validation of Deviancies in Social Responsiveness in Infants at Elevated Familial Risk for Autism Spectrum Disorder.

Introduction

The previous experimental chapters presented infant behaviour in two interactive eye-tracking studies (Chapter 3 & 4). The findings from the two experiments employing a gaze contingency paradigm suggest that relative to typically developing (TD) infants, infant siblings are less socially responsive when interacting with gaze-contingent stimuli. More specifically, infant siblings showed fewer contingent smiles and lower imitation rates compared to TD infants. Although our eye-tracking paradigms were designed to capture the interactivity of a real-life social interaction, the method lacks realism to a certain extent as the interaction does not include a live partner and takes place in a highly controlled lab setting. Furthermore, Risko and colleagues (2012) suggest that social attention in adults is fundamentally different in live and on-screen social stimuli and advocate for an empirical approach to examine concerns about ecological validity in eye-tracking research. Therefore, it remains relevant to examine infant behaviour within natural social interaction and compare this with the experimental findings from the eye-tracking task, particularly, considering the findings of reduced contingent responsiveness. As an additional benefit, the investigation of natural interaction provides the opportunity to study the behaviour of the interaction partner, in this case the parent. In this experimental chapter, I will present an analysis of video recordings of natural parent-infant interaction in infant siblings and I will examine to what extent reduced responsiveness in the eye-tracking tasks is reflected during natural social interaction.

Infant Siblings

Converging evidence suggests that relative to typically developing infants, infant siblings of children with autism spectrum disorder (ASD) present with subtle developmental differences in the first few years of life (See Chapter 2 for overview). Infant siblings of children with ASD are at elevated familial risk with approximately one in five infant siblings receiving an ASD diagnosis themselves, relative to 1.5% in the general population (Ozonoff, 2011b; Szatmari et al., 2016). Moreover, a considerable proportion of non-diagnosed infant siblings present with other developmental issues (Charman et al., 2017; Piven et al., 2018). A recent line of research has studied the development of infant siblings in an attempt to uncover endophenotypic markers for ASD. Knowledge on early behavioural manifestations of ASD is foundational for early diagnosis (Koegel et al., 2014; Zwaigenbaum et al., 2013), allowing for early intervention that can significantly improve prognosis (Dawson et al., 2010; Dawson et al., 2012; Fernell et al., 2013; MacDonald et al., 2014). Although a first-year marker with reliable predictive value remains elusive, research in the last decade has made considerable progression in the knowledge on potential developmental areas of deviance. Since ASD is classified as a predominantly social disorder (APA, 2013) and older children with ASD display several atypicalities within social interaction, such as diminished positive affect (Kasari et al., 1990) and reduced social responsiveness (Wetherby et al., 2007), several studies suggest that the earliest behavioural manifestations of ASD in infant siblings might present in the social domain (Bussu et al, 2018; Jones et al., 2014; Keemink et al., 2019; Keemink et al, *under review*; Schultz, 2005; Szatmari et al., 2016). Interestingly, Kanner (1943) mentioned an ‘extreme aloneness from the very beginning of life’ in his earliest descriptions of autistic behaviour. Infants’ earliest social experiences predominantly take place during interaction with their parents, making parent-infant interaction a relevant line of inquiry in this context.

Retrospective Research

Initial studies probing deviant behaviour during early social interaction employed retrospective methods such as analysis of home videos or parental reports. Converging evidence from studies analysing home videos from 6- to 30-months-old infants suggests that reduced visual orientation to social stimuli (Barenek, 1999; Osterling and Dawson, 1994), diminished social engagement (Bernabei, Camaigni & Levi, 1998; Mars, Mauk & Dowrick, 1998), disturbed reciprocity (Apicella et al., 2013) and reduced positive affect (Saint-Georges et al., 2010) during social interaction distinguish infants who later receive an ASD diagnosis from infants who will develop typically. Parents seem to be sensitive to the paucity of social engagement and tend to compensate for this by providing more directive invitations to interact (Baranek, 1999; Saint-Georges et al., 2011). Additionally, retrospective parental reports on the earliest symptomatology of ASD indicate that infants who are later diagnosed are characterised by social passivity and a lack of social engagement (Gillberg et al., 1990; Ozonoff, Williams & Landa, 2005; Ozonoff et al., 2011a; Watson et al., 2007).

Although these studies have provided important foundations for future studies, the retrospective nature of the research is arguably problematic as it is reliant on the restricted availability of recordings and on parental memory accuracy. Baranek (1999) acknowledges the methodological difficulties pertaining to retrospective video analysis, such as a lack of control over the recording quality and content, and Robbins et al. (1963) clearly illustrate the inaccuracy of parental reports. Moreover, correspondence between home videos and parental reports is far from optimal (Ozonoff et al., 2011a). To address these issues, researchers have endeavoured to prospectively study the emergence of autistic manifestations by following the socio-communicative development of infant siblings of children with an ASD diagnosis.

Prospective Research

Various recent studies have examined different aspects of infant-parent interaction comparing infant siblings and TD infants using a Parent-Child Free Play procedure in which parent and infant are video-recorded whilst playing freely with a set of provided toys. The results these studies have yielded are not dissimilar to findings from interaction studies with older children with ASD. For instance, from 12 months old, infant siblings show reduced visual attention to faces, fewer shared smiles and fewer vocalisations during interaction (Harker et al., 2016; Ozonoff et al., 2010; Rozga et al., 2011). Wan et al. (2013) report that infant siblings are less lively during interaction. Furthermore, reduced social engagement, fewer gestures and joint attention behaviours, and a lower quality and frequency of vocalisations during parent-infant interaction at 12 months predict ASD symptomology at age 3 (Campbell et al., 2015; Heymann et al., 2018; Paul et al, 2011; Rozga et al., 2011; Talbott et al., 2015;

Wan et al., 2013). Interestingly, studies including 6-month-old infants report typical functioning at this age, with deviancies not showing until the end of the first year (Ozonoff et al., 2010; Rozga et al., 2011), which aligns with findings from studies attempting to predict ASD diagnosis using other behavioural measures (Chawarska et al., 2014; Bussu et al., 2018). Only one interaction study reports no differences in social play behaviour between infant siblings and TD controls at 12 months (Steiner et al., 2018), although publication bias may have affected the publication of no-difference findings (Ferguson & Heene, 2012).

Parental Behaviour

Interactive behaviour does not occur in isolation, and in the first few years of life infants' caregivers are their main interaction partner. Examining parental behaviour within early interaction is therefore essential to obtain a complete understanding of infant behaviour within social interaction. Several of the aforementioned studies also include parameters of parental behaviour during interaction with their infant, investigating potential differences between parents of infant siblings and parents of TD infants. Collectively, the findings from these studies converge to conclude that there are no differences in parental social responsiveness during social interaction (Campell et al., 2015); both sets of parents are equally responsive (Harker et al., 2016; Leezenbaum et al., 2014; Schwichtenberg et al., 2018) and provide equal levels and quality of linguistic input (Talbott et al., 2016), although Wan et al. (2012) suggest that parents of infant siblings respond less sensitively toward their infants. However, mothers of infant siblings display more directive behaviour within interaction compared to mothers of TD infants (Harker et al., 2016; Wan et al., 2012). Steiner (2018) proposes this directive communication style is an active attempt by parents to expand the range of play of their less engaged infant. Similarly, Talbott et al. (2015) report that parents of infant siblings use more gestures, potentially in an attempt to engage their infant. These findings seem to suggest that parents of infant siblings are sensitive to their infant’s reduced social engagement and adjust their communication styles accordingly.

Indeed, Leezenbaum et al. (2014) posit that the input infant siblings receive from their parents may be altered by infants’ reduced social responsiveness. Although this suggestion seems plausible, it is complicated to tease apart the order of parental and infant behaviour. Due to the complexities of interaction it remains unclear if parents adjust their communication styles because of their infant’s reduced engagement, or if infants’ social responsiveness is affected by their parent’s alternative communication style. Wan et al. (2013) and Yirmiya et al. (2006) propose two other potential explanations to account for the relationship between infant behaviour and parental directiveness. Firstly, parents of infant siblings potentially adopt alternative communication styles because they are affected by the broader autism phenotype (BAP), often present in family members of individuals with ASD (Losh et al., 2008). Secondly, the communication style of parents of infant siblings might reflect their experience with their older child with ASD. In fact, research demonstrates that parents tend to show more directive behaviour in interactions with their older children with ASD (Crowell, Keluskar & Gorecki, 2019; Patterson, Elder, Gulsrud & Kasari, 2014), similar to interactions with infant siblings. Wan et al. (2013) note that these explanations are not mutually exclusive, and more research is needed to gain a better understanding of the intricacies of parent-infant interaction in families with children with ASD and infant siblings.

Although well-intentioned, there is some evidence suggesting that the directive communication styles parents intuitively adopt at 12 months might be negatively associated with infant social engagement at 18 months (Harker et al., 2016), which could lead to a negative cascading effect. However, the apparent notion that parents can affect their infant's socio-communicative behaviours does provide opportunities for early intervention. More recently, researchers have explored the impact of parent-led intervention for infant siblings demonstrating promising results (Green et al., 2013; Green et al., 2017; Rogers et al., 2014). These interventions are targeted at infant siblings in the first year of life before ASD symptoms are at the level of diagnosis. Effective components of intervention include increasing parental contingent responsiveness (Green et al., 2017), enhancing parent-infant synchrony (Green et al., 2013), as well as an individual approach to support parents and infants optimally (Green et al., 2013; Rogers et al., 2014). Follow-up results demonstrate the positive effect of preventative parent-mediated intervention extending to at least three years of age. These findings seem to suggest that parents of infant siblings are sensitive to their infant's level of social engagement and this can serve as foundation for intervention.

The Current Study

Taken together, the research reviewed thus far underlines the importance of early parent-infant interaction for infant siblings and illustrates that interactional settings have the potential to highlight deviant social responsiveness. In the previous two chapter (3 & 4), social responsiveness in infant siblings was examined using interactive eye-tracking tasks in which infants could elicit social responses from on-screen actors by engaging in eye contact. (Keemink et al., 2019; Keemink et al, *under* *review*). Infants were video recorded during these tasks to collect measures of social responsiveness, contingent smiling and imitation. The findings demonstrated that relative to TD infants, infant siblings present with lower rates of these socio-communicative behaviours. Building on these results, the current study aims to examine whether the infants presenting with reduced social responsiveness in the gaze-contingent eye-tracking task display similar behaviour in face-to-face interaction. Gangi et al. (2018) highlight the importance of examining infant sibling behaviour across different contexts to validate the experimental paradigms employed and to test the generalizability of findings. Furthermore, the investigation of socio-communicative behaviour across multiple interactional settings allows for the examination of the pervasiveness of social deviancies in infant siblings.

To this end, a sample of infant siblings and their parents will carry out a free play interaction task, which will be video recorded and coded. Subsequently, infant behaviour during the free play task and in the interactive eye-tracking task will be compared to investigate whether reduced social responsiveness during an interactive eye-tracking task generalises to a free play task, a situation that more closely approximates a real-world context. Furthermore, measures of parental social behaviour were collected to examine associations between parent behaviour and infant engagement. If the eye-tracking findings from the interactive eye-tracking tasks are meaningful and social atypicalities in infant siblings are pervasive, it is expected that the reported deviancies in social responsiveness during the eye-tracking task will be reflected in infant sibling behaviour during real-life interaction. Following from these aims it is hypothesized that low social responsiveness during the eye-tracking task will be associated with reduced social engagement during the free play interaction task.

Secondly, it is hypothesized that parental behaviour will vary as a function of infant social engagement levels.

Method

This study was approved by the Ethics Committee of The University of Kent (Ethics ID: 201815168322884850) and the NHS Health Research Authority (IRAS: 239237). All parents signed an informed consent for their participating infant. Data were stored and treated anonymously.

Participants

Infant siblings were recruited through the Kent Autistic Trust and the Community Child Health, East Kent Hospitals University NHS Foundation Trust. Infant siblings had at least one older sibling with an ASD diagnosis. All autistic siblings had received a formal diagnosis established by a clinical psychologist.

The final sample comprised 23 Caucasian infant siblings including 6-month-olds, 9-month-olds, and 12-month-olds. All infants also participated in an eye-tracking study (See Chapter 4 for study details). Table 1 presents a detailed overview of participant characteristics. For 22 infants the mother was present during the free-play interaction. For the one remaining participant, the father completed the task.

Note: Initially, I had planned on making the comparison between behaviour on the eye-tracking task and free-play task for typically developing infants as well. However, due the unprecedented circumstances of the pandemic I was no longer able to collect this data and therefore the chapter will exclusively focus on the examination infant sibling behaviour across the two research contexts.

Table 1

Participant Characteristics

Characteristic	N (Total = 23)
Age	
6 months	6
9 months	8
12 months	9
Sex	
Male	15
Female	8
Sibling(s) with ASD	
One	14
Two	5
Three	4

Stimuli

The Interaction Task. This task was modelled after the Parent-Child Free Play procedure used by several previous studies (Baker, Messinger, Lyons & Grantz, 2010; Carter et al., 2011; Harker et al., 2016). Parent and infant sat on the floor and were provided with a box of age-appropriate toys, including a rattle, two shakers, a xylophone, a hand puppet, a truck, a bus, a little spade, two soft toys and a sieve (See Figure 1). The experimenter instructed the parent to play as they would normally do at home and emphasized there was no right or wrong way to behave. Two video cameras were installed to record the interaction from two different angles for a duration of five minutes. The experimenter left the room during the recording.

Figure 1. A Mother and Infant Engaged in the Free Play Task.

The Gaze-contingent Eye-tracking Task. All infants participating in the free play interaction, also participated in the gaze-contingent eye-tracking task in which infants could trigger expressive responses from on-screen actors by engaging in eye contact (See Figure 2). All infants viewed 18 video-recorded, neutral-looking actors on a computer screen, who would produce expressions representing one of the six basic emotions (happiness, sadness, surprise, disgust, fear and anger) at the moment the infant engaged in eye contact with the actor. The expression produced by the actors was contingent on the infant's first fixation in the eye region. Infants were video-recorded during this eye-tracking task to collect measures of infant responsiveness, contingent smiling and imitation. Findings demonstrated that infant siblings presented with more deviant behaviour on these measures relative to TD infants. Therefore, these three measures will be included in the analysis of the current study to examine how they relate to behaviour in the free-play task. See Methods section Chapter 4 (p. 92) for additional details of the task.

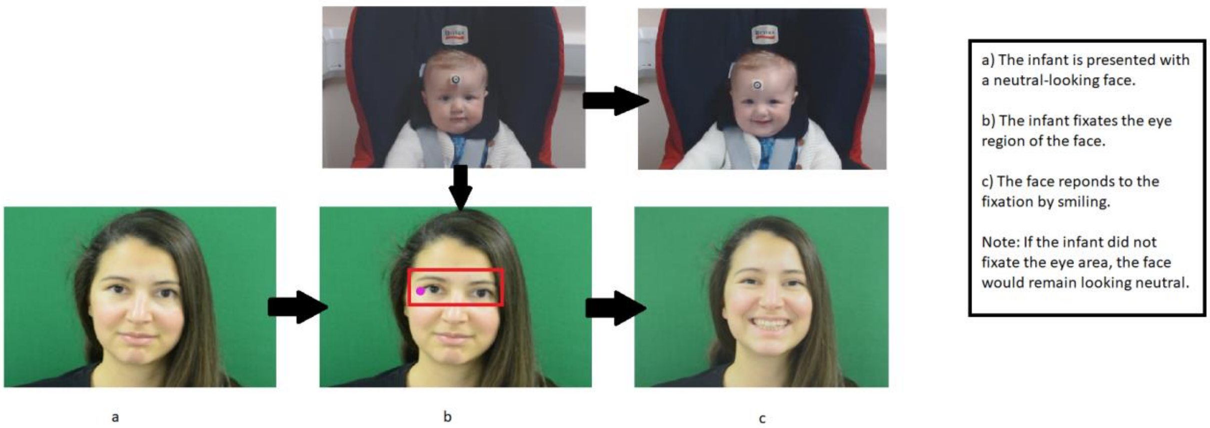


Figure 2. An Example of a Gaze-Contingent Stimulus plus Infant Response

Coding Scheme Development

From all recorded five-minute play sessions, a three-minute segment was selected for analysis, starting at the moment that the toys had been set up and the experimenter had left the room. This selection procedure was based on previous research (e.g. Wan et al., 2012) and video segments from earlier studies vary between 1 minute (Rozga et al., 2011) and 10 minutes (Blacher, Baker & Kaladijan, 2013). Following from previous research into parent-infant interaction (Anme et al., 2010; Blacher et al., 2013; Blazey, Leadbitter, Holt & Green, 2008; Campbell et al., 2015; Harker et al., 2016; Rozga et al., 2011), a coding scheme was developed. Infant measures were selected based on sensitivity to deviancies in previous studies and on relevance in relation to the eye-tracking task. Visual attention to faces, smiling behaviour and the use of vocalisations were repeatedly suggested as measures that yielded deviancies in infant sibling behaviour. Additionally, a rating of infant engagement was included to gauge the general nature of infant sibling behaviour during interaction. Finally, as the gaze-contingent eye-tracking task reflected the contingency inherent to social interaction, the current task comprised an overall rating of contingent responsiveness.

Parental measures were derived from measures employed in previous studies that seemed characteristic of the behaviour of parents with an infant sibling, namely directiveness and contingent responsiveness. Furthermore, parental measures of praise, social smiles and social vocalisations were included exploratorily to investigate how these behaviours related to infant sibling behaviour.

Videos were coded by the experimenter and two independent coders. All coders were unaware of the infants' performance on the eye-tracking task and thus could not be influenced by expectations about social responsiveness. Agreement between coders for the different measures were moderate to high (ICC = .72 - .85).

Measures

Infant Behaviour. Five measures of infant behaviour were collected. Social smiles (accumulative count) were coded if the infant smiled at their parent whilst making eye contact. Face looks (accumulative count) were coded if the infant looked at their parent's face during the interaction. Social vocalisations (accumulated count) were coded if the infant produced vocalisations directed at their parent. Two further measures were coded on a 4-point scale to the coders' discretion. Infant engagement, defined as the extent to which the infant was engaged in the play and interacted with the parent, ranging from not at all engaged (1) to highly engaged (4). Second, contingent responsiveness, defined as the extent to which the infant responded to the parent's play and interaction bids, ranging from never (1) to frequent (4).

Parental Behaviour. Five measures of parental behaviour were collected. Praise (accumulative count) was coded if the parent praised their infant during the interaction (e.g. well done, good girl). Social smiles (accumulative count) were coded if the parent smiled at their infant whilst making eye contact. Social vocalisations (accumulated count) were coded if the parent produced vocalisations directed at their infant. Two further measures were coded on a 4-point scale to coders' discretion. Directiveness, defined as the extent to which the parent controlled the play (as opposed to following the infant's lead), ranging from not at all directive (1) to highly directive (4). Second, contingent responsiveness, defined as the extent to which the parent responded sensitively to the infant's play and interaction bids, ranging from never (1) to frequent (4).

Eye-tracking Measures. For the present chapter, three measures derived from the video recordings taken during the gaze-contingent eye-tracking task (Chapter 4) will be used. Findings from Keemink et al. (*under review*) demonstrate that relative to TD infants, infant siblings are less responsive, show fewer contingent smiles and imitation when presented with expressive actors. Therefore, these measures will be included in the following analyses to examine if socio-communicative behaviour during the eye-tracking task generalizes to behaviour in the free play task.

Procedure

Infant and parent were welcomed in the child-friendly waiting room of the Kent Child Development Unit where they were informed about the details of the eye-tracking study and the interaction study and were presented with a consent form. After completing the gaze-contingent eye-tracking task in the lab, infant and parent were escorted back to the waiting room where they were reminded of the procedure of the interaction task. Subsequently, the experimenter left the room and parent and infant were video recorded for five minutes of free play interaction. When the experimenter returned, the cameras were paused, and the parent and infant were thanked for their participation. The parent received a tote bag and the infant received a toy and certificate as remuneration.

Results

Power Analysis

A priori power analyses for bivariate correlations were based on medium to large effect sizes and a power of at least .80. The required yielded sample size was 23. The current sample comprises 23 infants and therefore conforms with the power requirements.

Analysis Plan

This study comprised the following two aims. Firstly, this study aimed to investigate whether reduced social responsiveness during an interactive eye-tracking task generalises to a real-world context. To this end, three measures from the gaze-contingent eye-tracking task (overall responsiveness, contingent smiling behaviour, imitation) were correlated with the five infant measures from the current free-play task (social smiles, face looks, social vocalisations, engagement and contingent responsiveness). To further evaluate the relationship between social behaviour on the eye-tracking task and the free play task, a Principal Component Analysis (PCA) was conducted. PCA is a data reduction method and provides insight into which variables explain shared variance (Jollife & Cadima, 2016). It was argued that if correlated variables from the eye-tracking task and the free play task would load on the same factor, and thus explain shared variance, this would strengthen the evidence for a relationship between social behaviour on both tasks. Secondly, this study intended to examine associations between parent behaviour and infant engagement. For this purpose, correlations were computed for the five parental behaviours (praise, social smiles, social vocalisations, directiveness and contingent responsiveness) and the five infant measures from the free-play task. For an overview of the descriptive statistics of both infant and parent measures see Table 2.

Table 2

Descriptive Statistics for Infant and Parent Measures

Measure	Mean	Minimum	Maximum	SD
Infant smiles	2.09	0	8	2.45
Infant face looks	4.09	0	17	4.50
Infant vocalisations	4.52	0	15	4.33
Infant engagement	2.74	1	4	.86
Infant contingent responsiveness	2.39	1	4	.72
Parent praise	2.65	0	12	3.08
Parent smiles	3.70	0	11	3.89
Parent vocalisations	39.61	15	72	15.63
Parent directiveness	2.22	1	4	1.04
Parent contingent responsiveness	3.00	2	4	.74

Hypothesis 1: Relationship between Eye-tracking Task and Free-play Task

It was hypothesized that deviancies in social responsiveness during the eye-tracking task would be reflected in infant sibling behaviour during real-life interaction. Pearson's bivariate correlations were computed between the infant measures on the free-play task and the gaze-contingent eye-tracking task (See Table 3 for overview of correlations). One significant correlation was found. The variables 'infant contingent responsiveness' (during the free-play task) and 'contingent smiling behaviour' (during the eye-tracking task) were found to be positively correlated, $r(21) = .435$, $p = .038$. Infants who were less contingently responsive during the free-play task displayed fewer contingent smiles in the gaze-contingent eye-tracking task and vice versa.

Furthermore, the relationship between social behaviour on the eye-tracking task and the free play task was confirmed by a Principal Component Analysis extracting three distinct factors. ‘Infant contingent responsiveness’ and ‘contingent smiling behaviour’ were found to load on the same factor and therefore have a substantial amount of shared variance (See Factor 2, Table 4) further supporting an underlying relationship.

Table 3

Correlations for Infant Measures on the Free-Play Task and Eye-Tracking Measures

	Infant Smiles	**Infant Looks**	**Infant Vocalisations**	**Infant Engagement**	**Infant Contingent Responsiveness**	**Eye tracking Responsiveness**	**Eye Tracking Smiles**	**Eye Tracking Imitation**
Infant Smiles		.833**	.386	.419*	.288	-.383	.111	-.125
Infant Looks	.833**		.399	.579**	.408	-.256	-.099	-.165
Infant Vocalisations	.386	.399		.403	.310	-.242	.037	-.189
Infant Engagement	.419*	.579**	.403		.608**	-.057	-.170	-.399
Infant Contingent Responsiveness	.288	.408	.310	.608**		-.013	.435*	-.126
Eye tracking Responsiveness	-.383	-.256	-.242	-.057	-.013		.176	-.077
Eye Tracking Smiles	-.111	-.099	.037	-.170	.435*	.176		.593**
Eye Tracking Imitation	-.125	-.165	-.189	-.399	-.126	-.077	.593**	

** Correlation is significant at the 0.01 level (two-tailed)

* Correlation is significant at the 0.05 level (two-tailed)

Table 4

Factor Loadings Based on a Principal Components Analysis for the Infant Measures

	Factor		
	1	2	3
Infant looks	.862		
Infants social smiles	.802		-.375
Infant engagement	.796		.392
Infant vocalisations	.631		
Infant contingent responsiveness	.600	.546	.421
Eye-tracking: contingent smiling		.952	
Eye-tracking: imitation	-.394	.678	-.480
Eye-tracking: overall responsiveness	-.351		.747

Note: Factor loadings <.2 are suppressed

Additionally, the analyses yielded four significant correlations amongst the infant measures of the free-play task. The variables ‘infant contingent responsiveness’ and ‘infant engagement’ were found to be strongly positively correlated, $r(21) = .608$, $p = .002$. Infants who were more contingently responsive, were also more engaged during the free-play task and vice versa. Additionally, a strong, positive correlation was observed between ‘face looks’ and ‘social smiles’, $r(21) = .833$, $p < .001$. Infants who looked more at their parent’s face, displayed more social smiles during the free-play task. The measure ‘infant engagement’ was found to be positively correlated to ‘infant smiles’, $r(21) = .419$, $p = .046$, and to ‘infant face looks’, $r(21) = .579$, $p = .004$. Infants who scored higher on engagement, also displayed more smiles and face looks towards their parent.

Hypothesis 2: Relationship between Parent and Infant Behaviour

It was hypothesized that parental behaviour would vary as a function of infant social engagement levels. Pearson’s bivariate correlations were computed between the parent measures and the infant measures on the free-play task (See Table 5) for overview of correlations). Four significant correlations were found. A positive correlation was found between the variables ‘parent contingent responsiveness’ and ‘infant engagement’, $r(21) = .427$, $p = .042$. Infants who were more engaged during the play task, had parents who were more contingently responsive, and vice versa. Additionally, the variables ‘parent social smiles’ and ‘infant social smiles’ were found to be strongly positively correlated, $r(21) = .843$, $p < .001$. Infants and parents affected each other’s smiling behaviour positively. A positive correlation was also found between ‘parent social smiles’ and ‘infant vocalisations’, $r(21) = .477$, $p = .021$, and between ‘parent social smiles’ and ‘infant engagement’, $r(21) = .530$, $p = .009$. Lastly, a strong, positive correlation was observed between ‘infant face looks’ and ‘parent social smiles’, $r(21) = .835$, $p < .001$. Infants who looked more at their parent’s face, had parents who smiled more, and vice versa.

Furthermore, the analyses yielded one significant correlation amongst parent measures of the free-play task. The variables ‘parent contingent responsiveness’ and ‘parent directiveness’ were negatively correlated, $r(21) = -.472$, $p = .023$. Parents who were more contingently responsive during the interaction, displayed less directive behaviour, and vice versa.

Table 5

Correlations for Infant Measures and Parent Measures on the Free-Play Task

	Infant Smiles	Infant Looks	Infant Vocal.	Infant Engag.	Infant Cont. Resp.	Parent Praise	Parent Smiles	Parent Vocal.	Parent Direct.	Parent Cont. Resp.
Infant Smiles		.833**	.386	.419*	.288	-.026	.843**	-.064	.099	.126
Infant Looks	.833**		.399	.579**	.408	-.109	.835**	-.100	-.033	.150
Infant Vocal.	.386	.399		.403	.310	.144	.477*	.255	-.057	.085
Infant Engag.	.419*	.579**	.403		.608**	.016	.530**	.049	-.186	.427*
Infant Cont. Resp.	.288	.408	.310	.608**		.064	.336	-.244	-.360	.341
Parent Praise	-.026	-.109	.144	.016	.064		-.187	.310	.053	.399
Parent Smiles	.843**	.835**	.477*	.530**	.336	-.187		.132	.039	.222
Parent Vocal.	-.064	-.100	.255	.049	-.244	.310	.132		.209	.295
Parent Direct.	.099	-.033	-.057	-.186	-.360	.053	.039	.209		-.472*
Parent Cont. Resp.	.126	.150	.085	.427*	.341	.399	.222	.295	-.472*	

** Correlation is significant at the 0.01 level (two-tailed)

* Correlation is significant at the 0.05 level (two-tailed)

Discussion

The present study aimed to examine infant sibling social behaviour across two different research paradigms, a gaze-contingent eye-tracking task and a free-play task, to investigate if deviant social behaviour is consistent across contexts. Infant behaviour during a free-play interaction between parent and infant was compared with interactive behaviour video-recorded during the eye-tracking task used in Keemink et al. (*under review,* Chapter 4). Additionally, measures of parental behaviour during the free-play interaction were collected to study the relationship between infant and parent behaviour. The current findings contribute to the literature on cross-context examination of infant sibling behaviour, which is of vital importance to test the generalizability of findings and to validate the research paradigms we employ (Gangi et al., 2018).

Infant Sibling Behaviour across Contexts

Confirming the first hypothesis, the findings of this study demonstrate that there is a relationship between infant sibling behaviour during a gaze-contingent eye-tracking task and infant sibling behaviour in a free-play interaction with their parent. Infants who scored low on contingent responsiveness during the free play task, also displayed fewer contingent smiles in the eye-tracking task. Furthermore, both measures were found to have a common underlying factor. These findings suggest that socio-communicative behaviour observed in a gaze-contingent eye-tracking task generalizes to the more naturalistic context of live parent-infant interaction. Moreover, the apparent consistency of atypical social responsiveness demonstrates the pervasiveness of the deviancies observed in certain infant siblings, aligning with the notion that ASD is a *pervasive* disorder causing impairments that are noticeable across different contexts (APA, 2013).

Furthermore, these results highlight the validity of both the gaze-contingent eye-tracking task and the free play task to detect meaningful socio-communicative deviancies in infant siblings. Despite the significant progression in knowledge on potential early markers for ASD, a first-year marker with reliable predictive value remains elusive. One proposed reason for this is the inability of current research methods to detect early socio-communicative manifestations of ASD due to a lack of sufficiently socially demanding and realistically interactive stimuli (Bussu et al., 2018; Keemink et al., 2019). The gaze-contingent eye-tracking paradigm seems particularly innovative and appealing in this context as it provides the ecological validity of a real-life interaction, whilst maintaining scientific rigour. The demonstrated validity of the paradigm in the present study is a next step in the endeavour to develop a reliable and clinically usable method to detect precursors of ASD, essential for improved family support and child outcome (Fernell et al., 2013).

Parental Behaviour

The second hypothesis of this study stated that parental behaviour would vary as a function of infant sibling engagement. It was found that parental contingent responsiveness and infant engagement were positively related. Parents who scored higher on contingent responsiveness had infants who were more socially engaged and vice versa. Additionally, parental social smiles were positively associated with infant smiles, face looks and engagement. This result highlights the importance of parental contingent responsiveness, similar to results found in studies with TD infants

(Ainsworth et al., 1974). Evidently, causal relationships cannot be inferred from the present results, however, intervention studies with infant siblings (Green et al., 2017) and older children with ASD (Patterson et al., 2014; Shire, Gulsrud & Kasari, 2016) also identified increasing parental contingent responsiveness as an important and effective component of family interventions to improve social outcomes. Our research supports these findings and taken together these studies provide essential foundations for future preventative interventions and parent psychoeducation.

Although parental directiveness and contingent responsiveness are not mutually exclusive, our results show these behaviours are negatively associated. Previous studies comparing parent-child interaction in infant siblings and TD infants suggest that parents of infant siblings are more inclined to adopt directive behaviour (Wan et al.,2012), which has a potential negative effect on infant engagement (Harker et al., 2016). Leezenbaum et al. (2014) also posit that the input infant siblings receive from their parents may be altered by their infant's reduced social responsiveness. Although this suggestion seems plausible, it is complicated to tease apart the order of parental and infant behaviour. Due to the complexities of interaction it remains unclear if parents adjust their communication styles because of their infant's reduced engagement, or if infants' social responsiveness is affected by their parent's alternative communication style. Several other reasons are proposed for the observed level of parental directiveness such as parental stress, established interaction patterns with their older child with ASD or the broader autism phenotype often present in family members of individuals with ASD (Girolametto & Tannock, 1994; Losh et al., 2008; Wan et al., 2013; Yirmiya et al., 2006). Wan et al. (2013) note that these explanations are not mutually exclusive, and more research is needed to gain a better understanding of the intricacies of parent-infant interaction in families with children with ASD and infant siblings.

Limitations and Future Directions

Although this study provides evidence that deviant infant sibling behaviour extends across two different social contexts and that parent and infant behaviour are associated, there are suggestions for improvements. Firstly, the reported correlations are all of a healthy effect size, however, to strengthen these conclusions replication in larger sample size is required. Secondly, infants' socio-communicative behaviour is not restricted to the two presently examined contexts. To further advance the knowledge on the consistency of deviant infant sibling behaviour and to obtain a comprehensive understanding of infant sibling development, data should be collected in additional social contexts, most importantly, the home environment. Lastly, although this study provides evidence suggesting that infant contingent responsiveness could be a potential early marker for ASD, follow-up data in toddlerhood are required to establish the specificity and predictive value of the proposed marker (Piven et al., 2018).

As the current study comprises multiple correlations of different variables, it could be argued that correction for multiple comparisons is required to reduce the likelihood of a type I error. However, the practice of such corrections has been disputed (Rothman, 1990; Streiner, 2015) and there are reasons why this option was not adopted in the present study. Firstly, the application of corrections for multiplicity increases the possibility of a type II error substantially (Perneger, 1998; Rothman, 1990), and there is no reason to assume a type I error is more problematic than a type

II error. Secondly, multiplicity corrections imply that a result will be interpreted differently depending on how many other tests were performed. In the current study, this means that if only two variables had been compared, negating the need for correction and yielding the same correlation as reported here, this result would have been accepted as appropriate. Perneger (1998) asserts that such differential interpretation endangers the soundness of statistical inference. Finally, this study involved multiple correlations and correlations can be viewed as effect sizes. In other words, the relevance of the selected p-value relative to the size of the correlation could be contested (Schober, Boer & Lothar, 2018). Taken together, the notion of correction for multiple comparisons has been acknowledged, nevertheless based on the argumentation above, it was deemed inappropriate for the current study.

Conclusion

The current study provides evidence suggesting that deviant infant sibling behaviour is consistent across two different contexts and demonstrates the validity of the findings derived from the gaze-contingent eye-tracking paradigm and the free play task. For the progression of the literature on infant siblings, it is essential that behaviour is examined and replicated across different social contexts. This study extends previous results by consolidating earlier findings on early social deviancies in infant siblings and enhancing the knowledge on appropriate research methods in this field. Furthermore, our results advocate for psychoeducation on parental contingent responsiveness, aligning with recent intervention studies. The current findings provide important implications for early areas of ASD detection and intervention with the purpose of offering families the earliest and most appropriate care to optimise outcomes.

The experimental findings from the interactive eye-tracking task described in Chapter 4 were corroborated in the current chapter. This chapter therefore presents further evidence for the efficacy and validity of the gaze-contingency paradigm. The first three experimental chapters addressed the infant as an active participant within social interaction. The following and last experimental chapter to this thesis will shift its focus to the infant as an observer of others in interaction. It could be argued that in addition to active participation, observation also plays an important role in infants' social development. More specifically, the observation of other people engaged in interaction plausibly provides infants with archetypes of human conversations. Therefore, Chapter 6 aims to explore how much infants understand about basic interactional principles when observing everyday conversations.

Chapter 6

Observing Conversations: An Eye-Tracking Experiment Probing Infants' Understanding of Everyday Interactions.

Introduction

This thesis explores early socio-communicative behaviour within typical and atypical development, and thus far, I have demonstrated that the gaze-contingency paradigm is an effective research method to examine infant behaviour within a simulated interaction capturing the reciprocity and contingency inherent to social interactions in the real world (Chapter 3 & 4). Furthermore, Chapter 5 provided evidence suggesting that deviant infant sibling behaviour is consistent across two different contexts and demonstrated the validity of the findings derived from the gaze-contingent eye-tracking paradigm and the free play task. This first line of research focussed on social interactions in which the infant was an active interaction partner. However, social development does not only involve 'becoming an active interaction participant', but also includes the observation of interactions and the acquisition of knowledge about other people's interactions. Consequently, I proposed it would be interesting and relevant to explore what infants understand about social interactions they experience as a viewer. The present study explores to what extent TD infants follow human conversations and was conducted as a side project alongside the studies reported in the previous chapters. Similar to previous chapters, it was reasoned that knowledge on how behaviour presents in typical development can inform the study of atypical behaviour. The current study provides more knowledge on infants' understanding of everyday social interactions, which can serve as a future avenue for detecting aberrant behaviour that might be indicative of atypical development.

In day-to-day life, infants observe numerous interactions, which likely serve as a model for their understanding of how social interactions are typically performed. At a miraculous pace, infants grow into talking toddlers capable of holding conversations that closely resemble the structure of adult conversations (Levinson, 2016). Interestingly, we never explicitly tell children how exactly conversations work, and yet from early infancy, infants already engage in proto-conversations (Bruner, 1975). Arguably, the observation of other people engaged in interaction provides infants with archetypes of human conversations. The forthcoming eye-tracking study explores how much infants understand about basic conversational principles by presenting them with short cartoons, in which two characters have an everyday conversation.

Social Attention

From birth, infants are exposed to a wealth of social information. In the early years, infants predominantly learn about their social world through observation, in which attention and orientation play essential roles. In the literature on social attention, it is widely known that from the first few days of life infants preferentially orient towards faces and face-like stimuli (Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996) and this interest and ability increases over the first year of life (Frank, Vul & Johnson, 2009; Frank, Amso & Johnson, 2014; Haith et al., 1977; Kelly et al., 2019). For instance, Frank et al. (2009) found that between 3- and 9-months of age, infants' focus on faces increases measured with a free-viewing task in which infants watched clips of an animated film. When young infants attend to a face, they show a particular interest in the eye region (Di Giorgio et al., 2013; Haith et al., 1977; Hunnius & Geuze, 2004; Keemink et al., 2019; Maurer & Salapatek, 1976), followed by a shift in attention to the mouth region between 6 and 12 months of age (Oakes and Ellis, 2013; Tenenbaum et al., 2013), which is attributed to language learning (Lewkowicz & Hansen-Tift, 2012). When faces are presented in an array amongst other social stimuli, such as body parts and animals, six-month-old infants look longer at faces (Gluckman & Johnson, 2013). Similarly, Kelly et al. (2019) demonstrate that infants' eye movement differentiate quantifiably when viewing images of natural scenes with or without a person present. Furthermore, studies presenting infants with more complex, dynamic social scenes suggest that between 3 and 30 months old, infants increasingly direct their attention to the parts of a scene that are most socially relevant (Frank et al., 2012) with inter-subject consistency also increasing, meaning that with age infants tend to look at the same location at the same time (Franchak, Heeger, Hasson & Adolph, 2016). Collectively, these studies show that from early in life, infants are motivated to attend to social information in their environment, which is foundational for the development of more complex socio-communicative processes (Berenthal & Boyer, 2015; Frank et al., 2014). For instance, infants use social information to make inferences about others' goals (Gergely & Csibra, 2003; Henderson and Woodward, 2011) and others' social preferences (Fawcett & Liszkowski, 2012).

Conversations

One specific socio-communicative situation that infants are presented with on a day-to-day basis are conversations between others. Although infants learn much about social practice by being an active participant within social interaction (Berenthal & Boyer, 2015), monitoring others engaged in a conversation forms a critical and substantial source of social information. Arguably, when infants observe social interactions, they are presented with archetypes of human conversations, which implicitly teach them the rules associated with human social practice. Several eye-tracking studies have probed infants' attention when free-viewing conversations and report a predominant focus on the speaker (Von Hofsten, Uhlig, Adell & Kochukhova 2009; Augusti, Melinder & Gredebäck, 2010) that is dependent on age-related visual attentional abilities (Frank et al., 2014). However, a study by Schmitow and Stenberg (2015) employing a head-mounted camera suggests infants' attention is more distributed in naturalistic environments.

Although it is relatively clear what infants attend to when they are presented with interaction, much less is known about how much infants understand about what a typical interaction constitutes and what they expect about the way social interactions are performed. Plausibly, infants' observations of conversational interactions provide them with information about the rules and practicalities associated with human conversations, and manipulations of typical interactions can provide insight into infants' comprehension of these rules. A handful of eye-tracking studies suggests that young infants' eye movements do indeed demonstrate sensitivity to variations from typical interaction. Augusti et al. (2010) found that from 6 months old, infants make more gaze shifts when viewing two actors holding a typical face-to-face conversation compared to when the actors held a conversation standing back-to-back. This result could not be explained by gaze following, and the authors conclude that infants are capable of perceiving the socio-communicative difference between face-to-face and back-to-back conversations. Two other studies demonstrated that 12- and 13-month-old infants are sensitive to the use of incongruent emotions and affect within social interaction (Biro, Alink, Van IJzendoorn and Bakermans-Kranenburg, 2014; Choi & Luo, 2015). Similarly, a recent study by Soley and Sebastian-Galles (2020) found that 12-month-old infants have expectations about what type of speech is directed at different persons (e.g. infant-directed speech is *not* commonly directed at adults).

These studies suggest that infants in the first year of life are capable of detecting atypical patterns of interaction, however there are many aspects of social interaction that have not yet been studied. Furthermore, a number of these previous studies employed animated shapes as acting agents in social interaction. It is questionable whether such shapes are representative of the interactions that infants observe in day to day life. Lastly, all discussed studies probing infants' expectations about typical social interaction included relatively small sample sizes (12 to 16 per condition). Consequently, the current study will further examine infants' knowledge of typical social interaction using novel stimuli that more closely approximate human-like social interactions in a large sample (N = 273) of 6- to 12-month-old infants.

The Current Study

The current eye-tracking study aims to build on the aforementioned line of research by further examining what exactly characterizes infants' eye movements when viewing social interactions and particularly what infants' eye-movement patterns reflect about their understanding of typical social interactions. Specifically, the study will explore how much 6-, 9- and 12-month-old infants understand about basic conversational principles and in doing so, it aims to investigate how much infants know about what constitutes a realistic interaction partner by comparing their eye movements during an interaction between two human-like characters and an interaction between two object characters. Previous studies have shown that young infants can distinguish between objects and people and will respond differently to each category. Three- and six-month-old infants display positive affect towards interactive people, but not towards interactive objects (Ellsworth, Muir & Hains, 1993). This notion is supported by neurological studies showing objects and faces are processed differentially in the infant brain (Southgate, Csibra, Kaufman & Johnson, 2008). Additionally, 5- and 6-month-old infants are also able to distinguish between different categories of objects and hold different expectations about inert and self-propelled objects (Luo, Kaufman & Baillargeon, 2009). Furthermore, research suggests that 6-month-old infants already have a rudimentary understanding about animate properties (Rakison & Poulin-Dubois, 2011) and expect people to communicate with other people, but not with objects. Considered together, previous research leads to the hypothesis that infants' eye movements and fixations will be different for conversations between two human-like characters compared to conversations between two objects. Specifically, it was expected that when viewing human conversations, infants would predominantly focus on the faces of the characters, whereas it was expected that object conversations would fail to capture infants' attention in the same way and consequently their fixations would be less spatially focused.

To examine these processes, infants will view a series of cartoons in which two characters are having an everyday conversation. Infants will be presented with different manipulations of the characters' appearance to investigate their understanding of typical conversational practice, and more specifically, their understanding of animacy and what constitutes a typical interaction partner. This study uniquely includes several aspects of social development and attempts to replicate and extend previous research by employing novel stimuli capable of providing an in-depth analysis of the characteristics of infants' eye movements when viewing interactions over the course of the first year of life. Finally, relative to previous research in this field, this study will include a substantially larger sample of 6-, 9- and 12-month-olds.

Method

This study was approved by the Ethics Committee of The University of Kent (Ethics ID: 201815300505765037). All parents signed an informed consent for their participating infant. Data were stored and treated anonymously.

Participants

The sample comprised 273 typically developing, Caucasian infants consisting of 6-month-olds, 9-month-olds and 12-month-olds (See Table 1 for participant characteristics). For all age groups, a testing window of +/- 14 days from the target age was used. Infants were considered typically developing if they had not been born prematurely (<6 weeks) and had no health or psychological conditions. All infants were recruited through the Kent Child Development Unit database, storing families who have shown an interest in participating in research and who have consented to being contacted.

All 273 infants viewed two cartoons (each from a different condition) resulting in a doubling of the number of data files. The final number of data files was 530 due to the exclusion of 16 trials.

Table 1

Participants per Age and Condition

		N	Age in Months	Mean Age in Days (SD)	Age Range
Condition	Full	50	6	182.70 (8.13)	169-196
		64	9	272.90 (7.07)	264-281
		69	12	364.36 (9.78)	356-378
	Total	150			
	Still	56	6	181.44 (8.14)	170-194
		58	9	275.05 (7.88)	262-284
		57	12	363.03 (7.68)	354-374
	Total	186			
	Object	44	6	184.13 (8.01)	172-193
		64	9	271.46 (8.26)	266-282
		68	12	365.51 (10.03)	356-379
	Total	194			
Total		530			

Stimuli

Two sets of cartoons were created as stimuli; each cartoon comprised three different versions, resulting in six different videos. The first set of cartoons (See Figure 1A) presented a female character in a park and a second female character walking into the scene, greeting the first one. Subsequently, the two characters had a conversation in the park, after which the second character walked out of the scene again. The second version of this cartoon presented the same scene; with the only change being that the characters' mouths were not moving, so that it was unknown who was the speaking character. This condition was included to study the effect of knowledge about who is the speaker and who is the listener. In the third version, the characters had been replaced with two objects; a desk chair and a lectern to create a control version (See Figure 1). Infants heard the original conversation, and saw the objects move in a similar manner to the human characters. For this cartoon, the 'Face' area of interest (AOI) comprised 4.74% of the pixel space and the 'Body' AOI comprised 4.98%. The total length of this cartoon was 45 seconds, of which 30 seconds were spent in conversation.

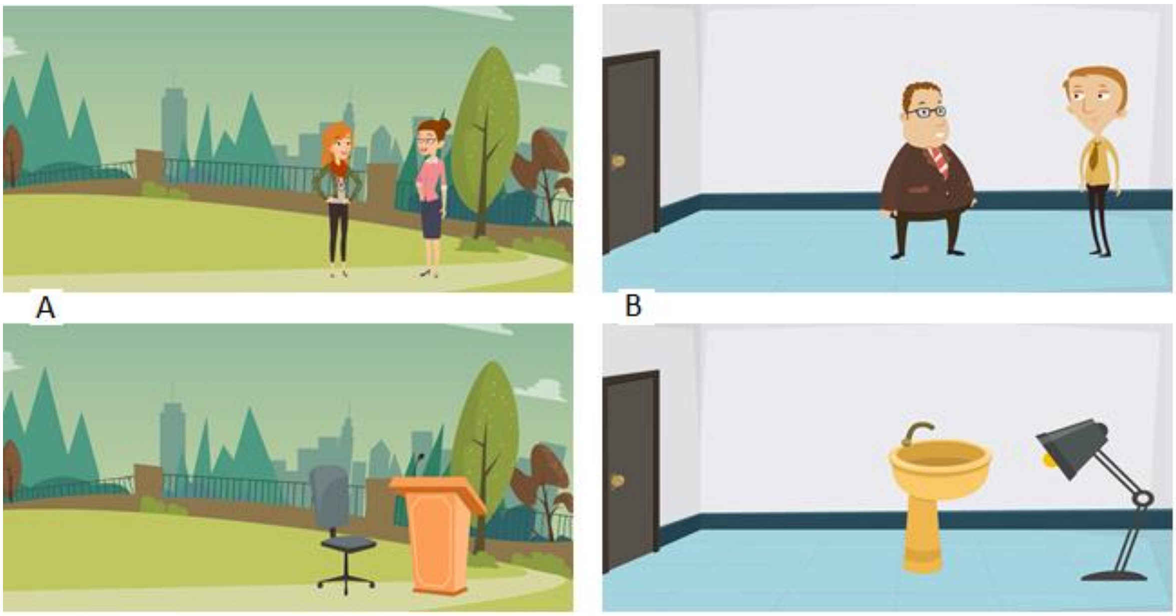


Figure 1. The Cartoon Stimuli.

The second set of cartoons (See Figure 2B) showed two male characters having a farewell conversation in a room, after which the character in suit leaves the room. The second version presented the same two characters; however, their mouths were not moving, so that it was unknown who was the speaking character. In the third version, the characters had been replaced by a sink and a desk lamp to create another control version (See Figure 1). Infants heard the original conversation, and saw the objects move in a similar manner to the human characters. For this cartoon, the 'Face' AOI comprised 5.71% of the pixel space and the 'Body' AOI comprised 6.79%. The total length of this cartoon was 30 seconds of which 15 were spent in conversation (See Figure 2 for transcripts of both conversations). For analyses purposes, the three versions of the animations were classified as three conditions: The Full condition, the Still condition and the Object condition. Infants only saw one condition of each cartoon (two cartoons in total), and presentation was counterbalanced.

The AOIs for each cartoon were the two bodies and the two faces of the interacting characters (See Figure 3). The same AOIs were used for the object condition. The third AOI, 'Other', comprised the remaining pixel space after deducting the 'Face' and 'Body' AOI. As the size of the pixel space for the AOIs of cartoon A was dissimilar to that of cartoon B, data for the two cartoons were adjusted for pixel space for analyses purposes. Preliminary analyses indicated that infants' eye movements did not differ for the female and male cartoons. Consequently, the data of the two different cartoons (female and male) were collapsed for the three conditions.

It is important to note that although this thesis endeavoured to introduce methods that closely approximate real-life interactions, the use of animated characters rather than real humans seemed justified in this experiment. Firstly, the use of animated characters allows researchers to have greater control over the stimulus presentation (Soley and Sebastian-Galles, 2020), which was particularly relevant in the current study for the creation of the control condition. By using animated characters, the different conditions could be kept exactly the same except for changes to the stimuli. This also permitted the manipulation of the movements of the object stimuli so that they would move in the same manner the human characters did. Secondly, the use of realistic animated characters is an improvement from previous research in this area, that has predominantly used animated shapes as acting agents within a social interaction (Biro et al., 2014; Hamlin et al., 2007; Mascaro & Csibra, 2012; Soley & Sebastian-Galles; Thomsen et al., 2011). Finally, the colourful, animated characters are visually appealing for the infant, facilitating sustained attention in an experiment presenting fairly long trials.

Who	Start	End	Text
Person 1	8.510876	9.505692	Hey, Robin!
Person 2	11.424086	12.224418	Hi, Jo!
Person 1	13.440923	14.433336	How are you today?
Person 2	15.988073	19.561859	I am good, thanks, how are you? The weather is lovely today, isn't it?
Person 1	21.112585	24.426145	I am well, thanks. You're right; the weather is wonderful.
Person 2	25.772834	30.091678	Ah good. Sorry, I have to go really quickly. I am seeing Hannah today.
Person 1	32.170068	34.260544	OK have fun, see you soon!
Person 2	36.181950	38.295624	It was lovely seeing you. See you later!

Who	Start	End	Text
Person 1	1.954806	3.740617	Well, it was really nice to meet you
Person 2	5.354302	7.829116	Likewise, and I'll be in touch about next week
Person 1	8.877891	9.700493	OK great
Person 2	11.980635	12.729206	I am off then
Person 1	13.842744	14.903311	Yes, bye!
Person 2	15.938821	16.413422	Bye!

Figure 2. Transcripts of the Conversations in Cartoon A and Cartoon B

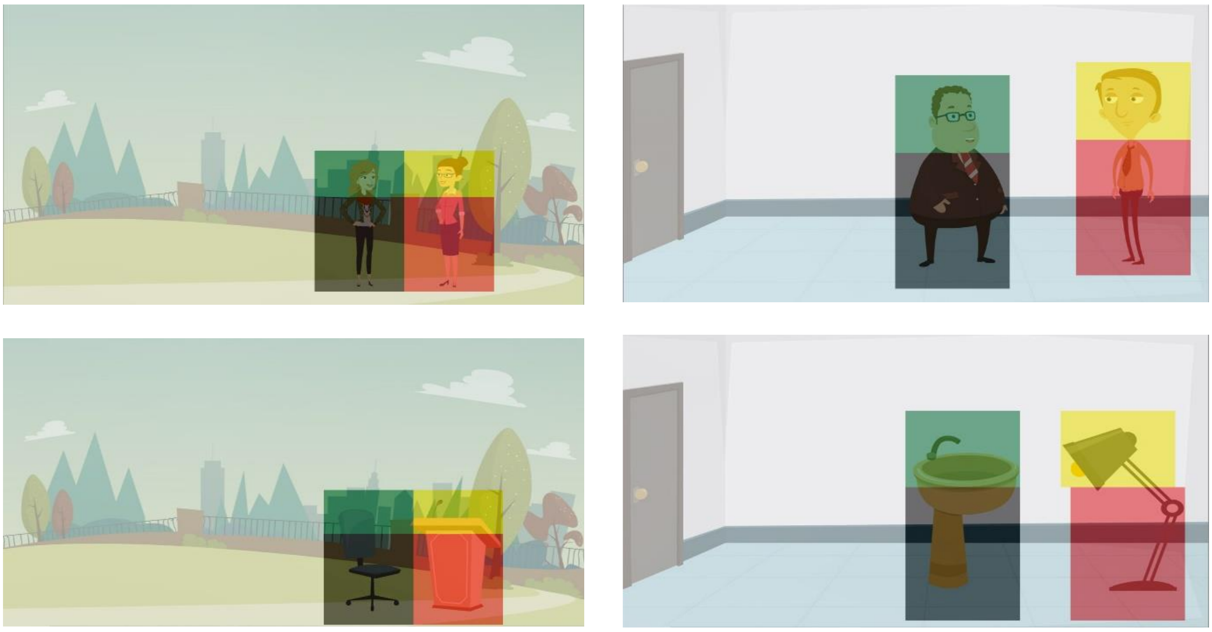


Figure 3. The Cartoon Stimuli with Areas of Interest.

Equipment

Eye-tracking equipment was identical to that of Chapter 3 (See page 64). Stimuli were designed using Animaker (Raghaven, 2014).

Procedure

The procedure of this study was identical to the procedure described in Chapter 3 (See page 64).

Eye movements

The algorithm used for this study was identical to that used in Chapter 4 (See page 98).

Results

Power Analysis

When data collection had taken place for a significant amount of time, post-hoc power analyses were conducted to evaluate whether the gathered sample yielded sufficient power. Post-hoc power analyses for repeated measures ANOVAs with 3 measurements (Areas of Interest: Head, Body, Other) and 9 groups (3 Conditions by 3 Age Groups) were conducted based on medium effect sizes and a power of at least .95. The required yielded sample size was 162 (N = 18 per group). Consequently, the current sample of 273 infants met the requirements for high power.

Analysis Plan

This study aimed to examine what infants' eye-movement patterns whilst viewing a social interaction reflect about their social understanding. Specifically, it will be investigated how much infants know about what constitutes a realistic interaction partner. To answer this question, analyses from both fixation data and eye movement data will be presented. Firstly, infants' fixations on three separate areas of interest (AOIs), namely Head, Body and Other, and eye movements for each of the three conditions (Full, Still, Object) will be analysed to examine differences per condition and age group. Secondly, infants' eye movements will be inspected to investigate difference in gaze shifting between conditions and age groups. Fixations and eye movements will only be analysed for the part of the conversation that was spent in conversation (See Method section). The data will be analysed with repeated measures and univariate ANOVAs, unless otherwise specified. For all AOIs, the significance level was set to 0.01, to compensate for multiple comparisons. Analyses revealed no effect of participant gender, so this factor was excluded.

Analyses of Fixation Data

It was hypothesized that infants' fixations would differ between the two conditions including a conversation between human-like characters (Full and Still condition) and the condition showing a conversation between two objects (Object condition). Specifically, it was expected that in the Full and Still condition, infants would predominantly focus on the faces of the characters, whereas for the Object condition it was expected that infants would show less spatially focused looking. Differences between the Full and Still condition were explored.

A 3 (AOI) x 3 (Age) x 3 (Condition) repeated measures ANOVA with AOI as within-subject factor and Age and Condition as between-subject factors was conducted. The dependent variable of these analyses was fixation time in seconds. Homogeneity of variances could not be assumed ($p < .001$), and therefore results will be reported with a Greenhouse-Geisser correction. A significant main effect of AOI was found, $F(1.713, 888.812) = 208.550$, $p < .001$, $\eta_p^2 = .287$. Infants distributed their fixations differently per AOI. Infants fixated most on the Head AOI ($M = 8.85$ seconds), followed by the Body AOI ($M = 3.84$ seconds) and the Other AOI ($M = 3.64$ seconds). There was also a significant main effect of Condition, $F(2, 519) = 10.774$, $p < .001$, $\eta_p^2 = .040$. On average, infants fixated significantly more in the Full ($M = 5.52$ seconds) and Still condition ($M = 5.92$ seconds) relative to the Object condition ($M = 4.88$ seconds), respective *p*-values were $p = .004$ and $p <.001$.

Additionally, the repeated measures ANOVA yielded three interaction effects. A significant interaction effect AOI x Condition, $F(3.425, 888.812) = 94.706$, $p < .001$,

$\eta_p^2 = .267$, demonstrated that infants' fixation patterns were similar for the Full and Still condition, but differed for the Object condition (See Table 2 for means). In the Full and Still condition infants looked significantly more at the Head AOI compared to the Body and Other AOI, whereas in the Object condition infants spent equal amounts of time fixating the three AOIs (See Figure 4, 5 & 6). Bonferroni post-hoc comparisons confirmed that fixations on the three AOIs did not differ between the Full and Still condition (all p-values > .35), but did significantly differ for all three AOIs between the Full condition and the Object condition, and between the Still condition and the Object condition (all p-values < .001).

Next, a significant interaction effect AOI x Age, $F(3.425, 888.812) = 5.390$, $p = .001$, $\eta_p^2 = .020$, demonstrated that the three age groups distributed their fixations differently to the Head and Other AOI. On average, twelve-month-olds fixated more on the Head AOI (M = 9.76 seconds) compared to 9-month-olds (M = 8.61 seconds) and 6-month-olds (M = 8.20 seconds). Consequently, twelve-month-olds fixated less on the Other AOI (M = 2.80 seconds), relative to 9-month-olds (M = 3.60 seconds) and 6-month-olds (M = 4.52 seconds). Lastly, a significant AOI x Age x Condition interaction, $F(6.850, 888.812) = 2.805$, $p = .007$, $\eta_p^2 = .021$ was found. Infants' distribution of fixation patterns towards the different AOIs in the three conditions varied per age group.

Table 2

Means of Fixation Times (in Seconds for each AOI per Condition)

Condition	*AOI*	*Mean(SE)*
Full	Head	11.11(.39)
	Body	2.68(.33)
	Other	2.78(.24)
Still	Head	11.77(.40)
	Body	2.94(.34)
	Other	3.04(.24)
Objects	Head	3.68(.40)
	Body	5.89(.34)
	Other	5.09(.24)

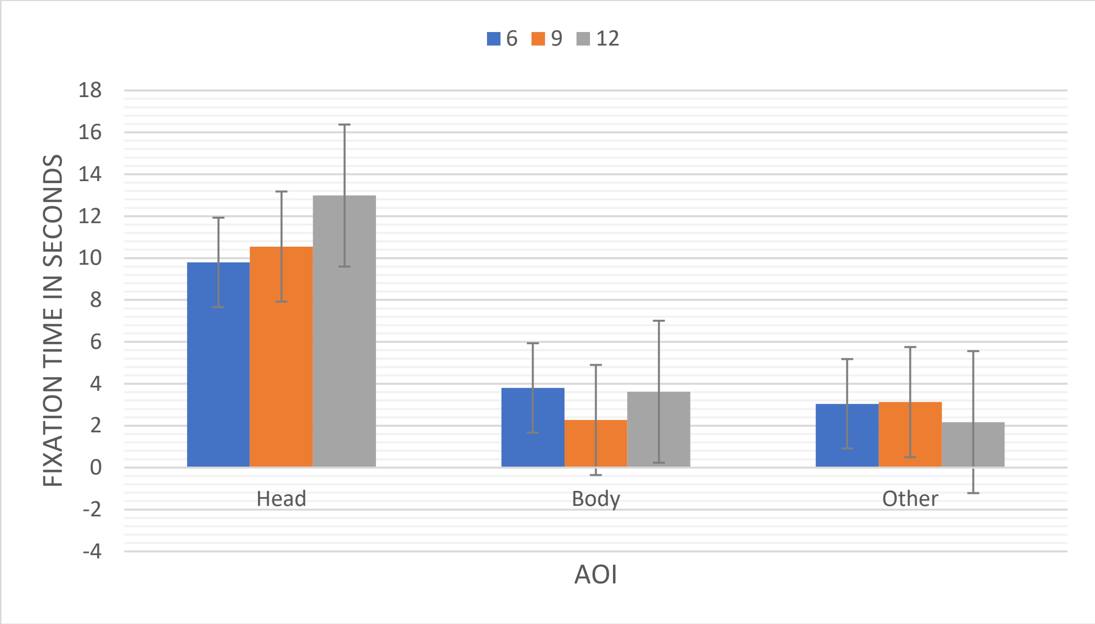


Figure 4. Fixations (in Percentages) on the Three AOIs per Age Group for the Full Condition

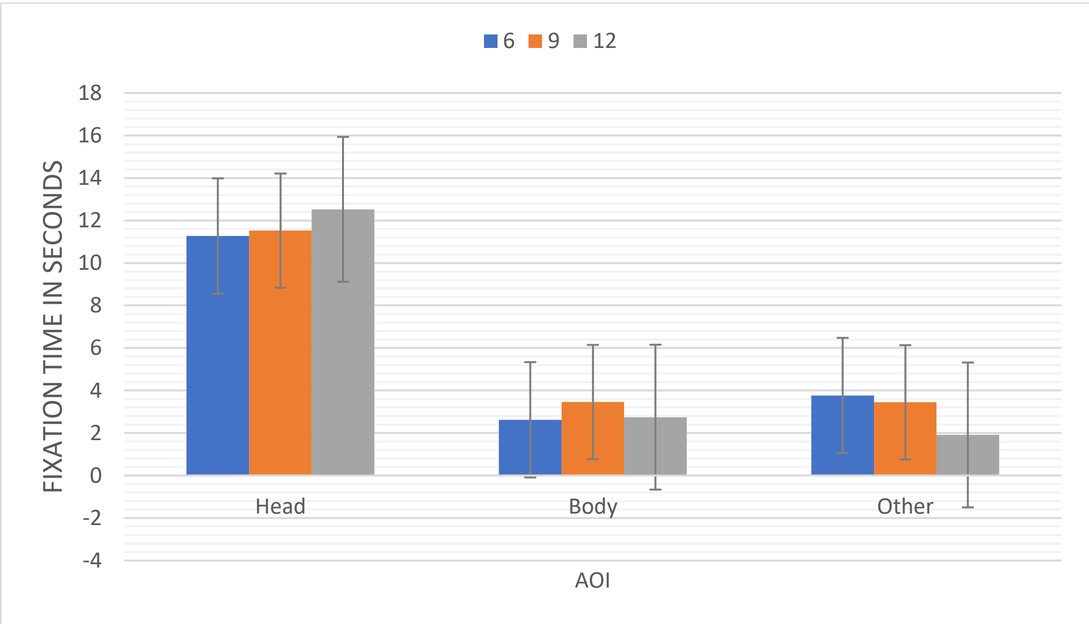


Figure 5. Fixations (in Percentages) on the Three AOIs per Age Group for the Still Condition

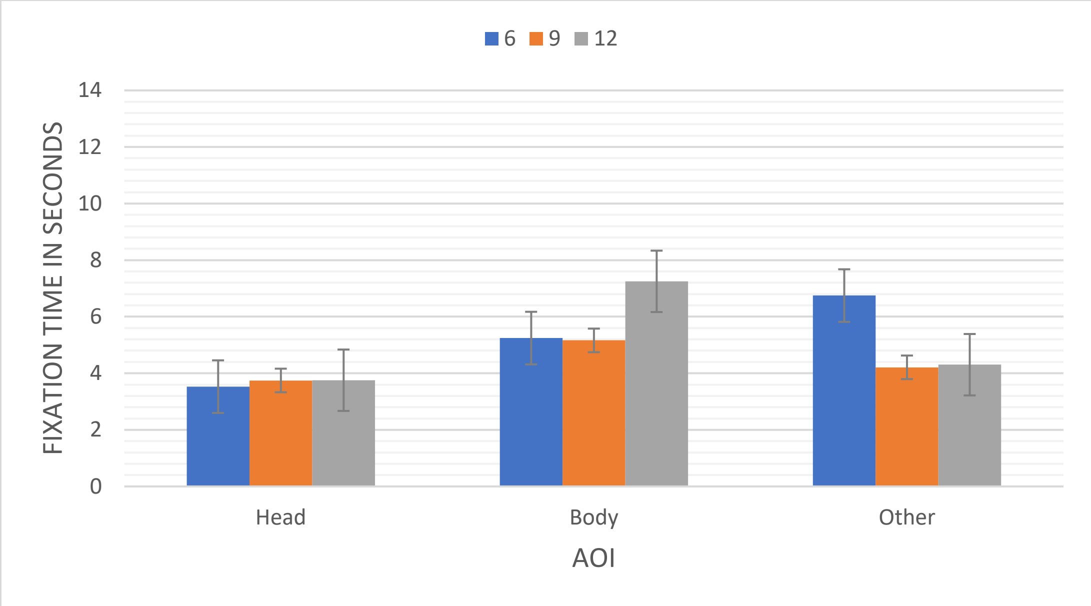


Figure 6. Fixations (in Percentages) on the Three AOIs per Age Group for the Object Condition

Analyses of Eye Movement Data

It was hypothesized that infants' eye movements would differ between the two conditions including a conversation between human-like characters (Full and Still condition) and the condition showing a conversation between two objects (Object condition). More specifically, it was expected that infants would demonstrate a more deliberate pattern of gaze shifts between human characters than object characters.

Analysis of eye movements corroborated the pattern found in the fixation data. The number of gaze shifts between characters during the conversation for the three separate conditions was analysed. A univariate ANOVA with the number of Shifts as dependent variable and Age and Condition as independent variables yielded a significant main effect of Condition, $F(2, 519) = 26.279$, $p < .001$, $\eta_p^2 = .092$. Infants made significantly more gaze shifts between interaction partners in the Full condition

(M = 7.97) and Still condition (M = 8.78) relative to the Object condition (M = 4.89), $p < .001$. Additionally, a significant main effect of Age was found, $F(2, 519) = 11.501$, $p < .001$, $\eta_p^2 = .042$. Twelve-month-olds (M = 8.51) made the most gaze shifts between characters followed by 9-month-olds (M = 7.35) and 6-month-olds (5.77), all p's < .05.

Discussion

The present study aimed to examine what exactly characterizes infants' eye movements when viewing social interactions and more specifically what infants' eye-movement patterns reflect about their understanding of realistic interaction partners. Infants were presented with cartoons displaying either human-like characters or object characters engaged in an everyday social interaction, whilst the audio of the conversation remained the same. Data were analysed in terms of fixation patterns and gaze shifts to examine differences across conditions. The current findings extend previous literature by examining an aspect of interaction that has not been studied before, by including a substantially larger sample of infants and by employing novel stimuli probing infants' understanding of realistic interaction partners.

Infants' Understanding of Human Conversations

It was hypothesized that infants' eye movements and fixations would be different for conversations between two human-like characters compared to conversations between two objects. The findings of this chapter confirm this hypothesis and demonstrate that infants' fixations and eye movement patterns are substantially different depending on the animacy of the characters engaged in conversation. In the Full and Still condition, infants looked significantly longer at the head of the character compared to the body and the rest of the scene, whereas in the Object condition, infants did not show a preference for fixating one of the AOIs. These results align with well-established findings on the face preference found in infants from birth (Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996). Furthermore, analysis of eye movements revealed that the number of gaze shifts infants made between the human characters was larger, both in the Full and the Still condition, than the number of gaze shifts made between objects, similar to Augusti et al. (2010). This suggests that infants attribute the reciprocity inherent to human social interaction more strongly to human characters than to object characters. The present result cannot be explained by infants' attraction to movement and biological motion (McKenzie & Day, 1976; Sifre et al., 2018), as the object characters had been manipulated in such a way that they moved in a similar manner as the human characters and at overlapping time points with the human animations. These findings confirm behavioural and neurological studies on infants' understanding of animacy demonstrating that from 6 months old, infants have a rudimentary understanding of animacy and show distinct responses to interactive people and interactive objects (Ellsworth et al., 1993; Luo et al., 2009; Rakison & Poulin-Dubois, 2011; Southgate et al., 2008).

Interestingly, previous research shows that infants readily make social inferences when presented with animated shapes with facial features or self-propelled motion (Hamlin, Wynn & Bloom, 2007; Mascaro & Csibra, 2012; Thomsen, Frankenhuis, Ingold-Smith & Carey, 2011). This suggest that infants do in certain contexts attribute social characteristics to objects. The objects in the current study moved in a self-propelled way, however, the comparison with human characters demonstrates that infants attribute more reciprocity and social communication to human characters than to object characters. Furthermore, the objects presented to infants in this study were realistic objects such as a lamp and a chair, potentially familiar to infants and eliciting different responses than arbitrary animated shapes. Previous studies have also presented such animated shapes in schematic, non-informative scenes (e.g. against a black background), whereas the present study showed characters within a realistic scene (e.g. the park). Such contextual clues might have facilitated the finding that infants assign social communicative signals to human characters more strongly than to object characters.

The results of the current study also converge with previous studies on infants' sensitivity to variations from typical interaction in the first year of life. More specifically, earlier studies showed that infants detect aberrancies in typical human interaction such as back-to-back conversations (Augusti et al., 2010), incongruent use of emotions and affect (Biro et al., 2014; Choi & Luo, 2015), and infant-directed speech directed at adults (Soley & Sebastian-Galles, 2020). The present study extends these previous findings by presenting evidence that infants in the first year of life are also sensitive to variations from typical interaction partners and hold some knowledge about typical conversational practice.

It is important to note that although there were three conditions included in this experiment, the Full, the Still and the Object condition, no differences were found between the Full and the Still condition. It was explored if the absence of mouth movements would affect the number of times infants made gaze shifts between the characters. Arguably, the audio of the interaction informed infants about potential gaze shifts. Inclusion of a condition without audio could provide a more definite answer about this. Nevertheless, both conditions demonstrated the distinction infants made between human and object characters.

Age Differences

Infant behaviour in this experiment using novel stimuli also revealed interesting age differences reproducing findings from earlier research. Specifically, 12-month-olds fixated more on the head of the characters and less on the rest of the scene compared to 6- and 9-month-olds. This finding replicates previous studies on attention to faces in the first year of life demonstrating that attention to faces increases over the first year of life (Amso, Haas & Markant, 2014; Frank et al., 2009; Frank et al., 2014). Additionally, 12-month-olds made the most gaze shifts between characters followed by 9-month-olds and finally 6-month-olds. Similarly, earlier studies in this area demonstrate that over the first year of life infants increasingly make more gaze shifts when viewing faces and become more proficient at anticipating turn-taking (Hunnius & Geuze, 2004; Keitel, Prinz, Friederici, Von Hofsten & Daum, 2013; Thorngrimsson, Fawcett & Liszkowski, 2015). The fact that the current study produced similar findings in a large infant sample strengthens previously reported conclusions on infants' attention to social stimuli in the first year of life and highlights the reproducibility of these findings.

Limitations and Future Steps

This study offered novel findings on infants' understanding of human social interaction in the first year of life, however, there are suggestions for improvements. Most notably, although the stimuli for the current study were designed to more closely approximate realistic social interactions relative to previous research using animated shapes, they do lack realism to a certain extent as they are cartoon characters. It can therefore not be unequivocally concluded that the findings from this study generalize to a real-world social context. There is some evidence suggesting that there are discrepancies between data on social attention derived from eye-tracking paradigms and data collected with head-mounted cameras in more natural settings (Schmitow & Stenberg, 2015). This notion warrants further investigation to fully understand the extent to which eye-tracking studies using human avatars to examine social development are representative of social situations in the real world. Although it is encouraged that researchers endeavour to produce research findings that are generalizable to a real-world context, the advantages of controlled lab settings must be taken into account. For the current study specifically, the presentation of an interaction between two cartoon characters rather than a live conversation between two actual human beings allowed for the manipulation of the characters without changing any other factors of the presented scene. Soley and Sebastian-Galles (2020) propose a similar argument, arguing that the use of animated characters rather than real humans allows researchers to have greater control over the stimulus presentation. Researchers need to carefully consider the implications of the type of stimulus they select and draw their conclusions accordingly. To gain more insight into how stimulus type affects infants' responses, larger comparative studies including several types of stimuli are required.

Conclusion

The current study presented novel knowledge on infants' comprehension of everyday conversations. The findings showed that infants aged 6- to 12-months show a basic understanding of what constitutes a realistic interaction partner as they preferentially looked at the faces of the characters only in the conditions with human characters and attributed reciprocity more strongly with human characters than object characters. In the gaze-contingent experiments in Chapter 3 and 4 of this thesis, it became evident that infants are sensitive to and respond to reciprocity when engaged in an interaction themselves. Considered together with the findings of the current chapter, this suggests that to certain extent 6- to 12-month-old TD infants understand socio-communicative intent both as an active participant and as a passive observer of human social interaction. In future studies, the findings of the current chapter can be utilised as comparison against an infant sibling sample to examine potential early differences in conversation following.

This chapter thereby concludes the experimental part of this thesis. The following and final chapter will summarise and critically discuss the findings presented in this thesis and will provide recommendations for future research.

Chapter 7

General Discussion, Limitations and Future Directions

This thesis introduced research methods that more closely approximate the interactive context in which social interaction typically occurs and attempted to contribute to both the knowledge on typical development and early manifestations of autism spectrum disorder (ASD). The first chapter provided an overview of typical social development in infancy, presenting evidence demonstrating that from the very first months of life, infants preferentially orient towards faces (Farroni et al., 2002; Johnson et al., 1991; Mondloch et al., 1999; Valenza et al., 1996), smile in response to social stimulation (Anisfield, 1982) and seek mutual engagement (Hilbrink et al., 2015; Salley et al, 2016). Extensive knowledge on typical patterns of social development is foundational for the detection of atypical development, and researchers must continue to scrutinize their research methods to ensure that findings on typical development are meaningful and generalizable to real-world contexts.

Human development does not always follow its typical course and the second chapter of this thesis illustrated this notion by discussing autism spectrum disorder, a pervasive developmental disorder characterised by significant impairments in social interaction and communication (APA, 2013). Currently, ASD is not reliably diagnosed before two years of age (Steiner et al., 2011). Furthermore, the median age of diagnosis of ASD in the UK is 55 months of age (Brett et al., 2016), and a very recent UK study confirmed that most children are not diagnosed until after school entry (Hosozawa et al., 2020), despite research underlining the importance of early intervention for later outcomes (Dawson et al., 2012; Fernell et al., 2013). In an attempt to lower the age of diagnosis, researchers have started to prospectively study the development of ASD by following infant siblings of children with an ASD diagnosis. These infants are at elevated familial risk to receive a diagnosis themselves (Ozonoff et al., 2011). Chapter 2 provided a detailed description of the research on infant siblings conducted thus far and concluded that although considerable progression has been made in the knowledge on early manifestations of ASD, a reliable first-year marker remains elusive. In this thesis, I proposed that in order to reliably identify first-year manifestations, we need to carefully consider the appropriateness of the research methods we employ, as the methods used thus far might not be representative of the interactive context in which social behaviour occurs in day to day life. Taken together, it became evident that research on both early typical and atypical development could benefit from the development of more interactive research methods.

7.1. The Gaze-Contingency Paradigm

To address the issue of inappropriate research methods in infant sibling research, Chapter 3 introduced a novel research method, the gaze-contingency paradigm, in which infants could trigger social responses from on-screen actors by fixating a certain prespecified region of the face, providing a more interactive and socially demanding experience (Keemink et al., 2019). By contrast, previous research has mostly presented infants with static images (Di Giorgio et al., 2013; Oakes and Ellis, 2013) and videos of faces (Hunnius and Geuze, 2004; Lewkowicz & Hansen-Tift, 2011; Tenenbaum et al., 2013). These studies have overlooked the contingency and reciprocity inherent to social interaction, whereas the gaze-contingent stimuli provided these critical elements. As this method had never been used before in infant face scanning research, this chapter aimed to establish how typically developing (TD) infants respond to interactive gaze-contingent faces. It was reasoned that this knowledge could subsequently be used as a norm of typical behaviour against which infants at elevated risk for atypical development could be compared. In this first gaze-contingent experiment, infants could elicit a socially engaging response (an open or closed smile) or a socially disengaging response (a head-turn or closing of the eyes) by fixating the eye region or mouth region of the on-screen face. It was hypothesized that infants would learn the contingency of the paradigm, seek out socially engaging responses and display a behavioural response that was congruent with the interactive response from the on-screen actor. Eye-tracking data and video-recorded behavioural response data were collected in a large sample of TD infants. It was found that all infants showed a clear eye preference, replicating findings from previous research using non-interactive stimuli (e.g. Haith et al., 1977). This persistent eye preference prevented infants from explicit contingency learning, however, infants did show evidence of implicit contingency learning. Analysis of saccadic latencies indicated that the saccadic response times of infants who triggered socially engaging responses were decreasing during the experiment, whereas for infants who triggered socially disengaging responses the saccadic response times increased. Thus, infants' eye movements demonstrated their sensitivity to the contingency of the paradigm, and more specifically to the different social responses from the actors. In addition to incorporating contingency, the gaze-contingency paradigm included a measure of reciprocity by video-recording infants' behavioural responses. Findings demonstrated that the interactivity of the paradigm encouraged infants' active engagement and clearly facilitated infant responsiveness. Infants showed distinct responses towards socially engaging and socially disengaging actors, suggesting they were susceptive to the difference in social meaning. Considered together, the eye-tracking findings and the behavioural response data suggest that the gaze-contingency paradigm succeeded in the aim of providing a socially demanding and interactive experience for infants and therefore extended previous research in this area.

With the norms for typical behaviour in the gaze-contingent task established, the behaviour of a small sample of infant siblings of children with ASD was contrasted with the typical norms to explore if the interactive gaze-contingent task was capable of detecting early differences in responses to social stimuli between TD infants and infant siblings. Previous research into face scanning in infant siblings has produced mixed results (e.g. Chawarska et al., 2013; Young et al., 2009), arguably due to the use of *non*-interactive face stimuli disregarding the contingency and reciprocity inherent to social interaction. Importantly, children with ASD show difficulties with contingency learning and reciprocity (Constantino et al., 2000), further highlighting the relevance of incorporating these processes in the research methods employed in infant sibling research. The distribution-based analysis approach from Chapter 3 suggested that relative to typical norms, infant siblings show more deviancies on the measure of dwell time on eyes, which aligns with earlier results (Merin et al., 2007). The sample size of the infant sibling participant group presented in Chapter 3 (N = 11) warrants caution for the interpretation of these preliminary findings, and further research in a larger sample was recommended. Nevertheless, the gaze-contingency paradigm was capable of highlighting infant siblings of interest in a small sample, which indicates its potential utility for infant sibling research.

7.2. The Gaze-Contingency Paradigm Extended

Chapter 4 sought to extend the first gaze-contingent experiment by including a larger infant sibling sample and by introducing novel interactive stimuli. Infants were presented with on-screen actors who would produce one of six basic emotional expressions (happiness, anger, surprise, fear, disgust, and sadness; Ekman, 1973) provided that infants engaged in eye contact with the actor. This chapter firstly endeavoured to further explore infant sibling behaviour in a gaze-contingent task. Examining how interactive emotional expressions are processed is particularly relevant for infant siblings, as research suggests that older children with an ASD diagnosis experience difficulties with emotion processing (Begeer et al., 2008; Dapretto et al., 2006; Rosset et al., 2007). Furthermore, several studies utilising *non-interactive* face stimuli suggest emotion processing in infant siblings could be a potential endophenotypic marker (Blasi et al., 2015; Fox et al., 2013; Mattson et al., 2013; McCleery et al., 2007; Wagner et al., 2016). Additionally, including a larger sample of infant siblings it was examined whether eye movements alone are suitable to reveal differences between TD infants and infant siblings, or if video-recorded behavioural responses would be more insightful. A second aim of Chapter 4 was to examine emotion comprehension in TD infants. A large body of research has investigated emotion discrimination and categorisation in TD infants (e.g., Addabo et al., 2018; Hunnius et al., 2011; Ludemann, 1991), however, emotion comprehension has been addressed relatively little in previous studies (Philips et al., 1990; Soussignan et al., 2017). The combination of the interactive gaze-contingent stimuli and the addition of video-recorded behavioural responses during an eye-tracking task allowed for the investigation of early emotion comprehension in a meaningful way.

The findings of this chapter demonstrated that infants, regardless of risk status, displayed expression-specific eye movements. For all infants, fixation patterns revealed that they are capable of perceiving visual differences between expressions, providing evidence of emotion discrimination in line with previous research (e.g., Hunnius et al., 2011). In terms of the development of early emotion comprehension, analysis of video-recordings demonstrated that infants are not providing behavioural responses that suggest conceptual understanding of emotional expressions at this age (6 to 12 months old). The only exception was 'happiness', which infants clearly reciprocated with a smile. Thus, the development of emotion comprehension seems to follow a more protracted course, extending beyond the first year of life.

Additionally, analysis of video-recorded behavioural responses provided evidence of differences between TD infants and infant siblings. Analysis of individual infant sibling behaviour demonstrated that relative to TD infants they show lower overall responsiveness, characterised by fewer smiles and less imitation. These findings aligned with research studying infant sibling responsiveness within parent-infant interaction (e.g., Rozga et al., 2011; Wan et al., 2013). These findings also extended findings from Chapter 3, and provide further evidence suggesting that the gaze-contingency paradigm can be implemented to detect early differences in behaviour between infant siblings and TD infants. The behavioural findings compellingly underlined the value of video recordings during eye-tracking tasks as a measure of early behavioural differences in infant siblings. The behavioural measures offered an in-depth analysis of the interaction and enabled the detection of subtle socio-communicative differences. Nevertheless, it remains important to be critical of the obtained results and discuss potential limitations. The attenuated social responsiveness observed in infant siblings, attributable to their reduced smiling response, was viewed as a response, or absence of a response, to the presented interactive faces. In order words, it was concluded that infant siblings show reduced smiling when exposed to interactive faces. It is, however, possible that infant siblings have lower smiling rates in general, and that the observed effect in this experiment is not meaningfully related to specifically face scanning. There is some research that suggests 12- and 18-month-old infant siblings with ASD express less positive affect overall (Filliter et al., 2015; Nichols et al., 2014). Further research is needed to examine this hypothesis. Preferably, data would be collected in both the gaze-contingency paradigm, and the home environment. Furthermore, different gaze-contingent stimuli could be employed to evaluate if reduced smiling occurs in multiple contexts.

Interestingly, analyses of eye movements yielded no meaningful differences between TD infants and infant siblings suggesting that visual exploration of interactive faces in infant siblings is typical. Earlier research has presented a mixed pattern of results with some studies concluding differences in fixation patterns between TD infants and infant siblings in a face scanning task (e.g., Chawaraska et al., 2013; Merin et al., 2007) and others reporting typical face scanning in infant siblings (e.g., Key & Stone, 2012; Wagner et al., 2018). As discussed in introductory Chapter 2, these studies all employed non-interactive stimuli, incapable of capturing the interactivity inherent to everyday social interaction, which potentially explains the contrasting results. The findings presented in Chapter 3 and 4 were derived from a realistically interactive and more socially demanding research paradigm and suggest that analysis of eye movements may not be sufficient to detect early differences. There are however other explanations to consider. Firstly, it could be proposed that infants need more experience with faces for differences in face scanning patterns to become more pronounced. Research with older individuals with ASD shows that they rely on different scanning strategies when scanning faces compared to neurotypical adults, however, did does significantly affect their performance on for example face recognition (Jemel, Mottron & Dawson, 2006). Accordingly, it might not be the most meaningful line of research to detect early markers. The research presented in this thesis suggests that behavioural responses whilst interacting with faces might be more informative than scanning strategies.

Alternatively, the lack of difference in eye-tracking findings could potentially be attributed to the level of social content presented to the infant. It is possible that the differences in fixation patterns do only emerge when the social content adheres to certain levels of 'social intensity'. A meta-analysis of eye-tracking studies examining social attention in adults with ASD concluded that differences relative to neurotypical adults were most pronounced when stimuli included more than one person (Chita-Tegmark, 2016). Similarly, Chevallier et al. (2015) demonstrate that stimulus type has a significant impact on the ability to detect group differences in social attention between children with and without ASD, and the task including multiple people in a naturalistic context was most sensitive. To rule out this explanation, this hypothesis could be tested using gaze-contingent stimuli presenting more than one person per trial.

When a novel paradigm is introduced, it is essential to reflect on the operating components and their importance in order to optimise research methods and to strengthen conclusions. In the context of the gaze-contingency paradigm, the significance of the gaze-contingent element could be questioned. Would a non-gaze-contingent, dynamic face, whose movements were meticulously timed to the average time it takes infants to trigger the gaze-contingent animation, elicit similar behavioural responses from infants? In other words, is the gaze-contingent element crucial to provoke a behavioural response in infants? To gain a deeper understanding of how the gaze-contingency paradigm functions, this is a relevant question to study. This could be realised by comparing infants' responses to both gaze-contingent and non-gaze-contingent dynamic stimuli. However, methodologically, the gaze-contingency paradigm has considerable strengths. Not only does it allow for the measurement of social contingency learning, it also provides the opportunity to guide infants' looking behaviour. Furthermore, extensive experience and observation of infants during lab testing suggest that infants display distinct responses to the gaze-contingent stimuli. Nevertheless, to obtain a more definite answer about the necessity of the gaze-contingent element, this needs to be studied further.

In addition to scrutinising the significance of the gaze-contingent element, variations to the method could be introduced to gain a further understanding of infants' behaviour within this paradigm. Firstly, the gaze-contingent manipulation could be examined further by making the effect continuous (i.e. when an infant looks away from the gaze-contingent area after triggering a response, the face returns to a neutral expression). This could provide more insight into infants' motivation to seek out or avoid the social response, and how this relates to the specific response programmed, which might be especially interesting with regards to the infant sibling cohort., considering the social difficulties pertaining to ASD. Secondly, variations in trial length could be explored. The trials in the current thesis were no longer than 5 seconds. It could be argued that longer exposure to the gaze-contingent stimuli could facilitate explicit contingency learning and could potentially enhance the understanding of differences between TD infants and infant siblings by exploring whether differences change or become more pronounced. The gaze-contingent method has great potential as a method in developmental research, but needs further investigation to fully understand its merits and drawbacks.

Considered together, the findings from Chapter 3 and 4 provide evidence that the gaze-contingent paradigm succeeded in providing an interactive experience capturing measures of contingency and reciprocity. Infants were actively engaged in the task. Furthermore, video-recorded behavioural responses seemed best suitable to detect subtle differences in social behaviour between TD infants and infant siblings.

7.3. A Novel Analysis Approach

In both Chapter 3 and 4, it was proposed that differences between TD infants and infant siblings should not only be studied at the group level, but also at the individual level introducing a novel distribution-based analysis approach. The main argument for this novel analysis approach is the proposition that infant siblings cannot yet be categorised as a uniform group separate from TD infants, as their developmental outcomes will vary significantly. Notably, the majority of infant siblings will develop typically without clinical level issues (Ozonoff et al., 2011), although there is variation present within this group (Brian et al., 2014). Furthermore, the infant siblings that do present with syndromic symptoms appear to have varying developmental trajectories (Landa et al., 2012). It therefore seems problematic to treat infant siblings as a homogeneous group and the invariable use of group-level analyses might bias infant sibling research. Due to the small size of the infant sibling sample in Chapter 3 it was not meaningful to conduct group-level analyses, but Chapter 4 illustrated the difference in analysis outcome between group-level and individual-level analyses. Whereas differences in imitation and smiling yielded significance at group level, responsiveness did not. However, looking at individual behaviour, our results revealed that the frequency of deviant behaviour on all three measures is higher in infant siblings when viewing interactive emotional faces. Medical research on clinical trials corroborates the importance of the distinction between individual- and group-level analysis, and underlines that an exclusive focus on group-level differences can lead to a failure to detect meaningful differences (Berlin, Santanna, Schmid, Szczech & Feldman, 2002; Riley, Lambert & Abo-Zaid, 2010). The results from this thesis commend a wider adoption of individual level analyses to ensure that the knowledge on potential early differences between TD infants and infant siblings is as unbiased as possible.

7.4. Cross-Context Examination

Chapter 5 sought to further examine the findings of reduced social responsiveness in infant siblings. Although the interactive face stimuli used in the gaze-contingent eye-tracking paradigm were designed to approximate the reciprocity and contingency inherent to real-life social interaction and clearly advanced previous research employing non-interactive face stimuli, the method lacks realism to a certain extent as the interaction does not include a live interaction partner and takes place in a highly controlled lab setting. To address this issue, Chapter 5 aimed to establish whether reduced responsiveness in the interactive eye-tracking paradigm extends to a real-life interaction. A cross-context examination of infant sibling behaviour is pivotal to establish the generalizability of findings and to validate the research paradigms we employ (Gangi et al., 2018). Furthermore, Risko and colleagues (2012) suggest that social attention in adults is fundamentally different for live and on-screen social stimuli and advocate for an empirical approach to examine concerns about ecological validity in eye-tracking research. To this end, in Chapter 5, infants were video recorded during a free play task with their parent. These data were subsequently compared to findings from the gaze-contingent eye-tracking task to examine cross-validity. Previous studies probing social behaviour in both TD infant and infant siblings during parent-infant interaction seem to suggest that infant siblings are less responsive and engaged (e.g., Harker et al., 2016; Ozonoff et al., 2010; Wan et al., 2013), similar to the findings of reduced responsiveness reported in the eye-tracking task of Chapter 4. In the study presented in Chapter 5, infant and parental behaviour were coded for measures of social responsiveness, and these measures were correlated with the findings from Chapter 4.

The findings demonstrated that a relationship was found between infant sibling behaviour during a gaze-contingent eye-tracking task and infant sibling behaviour in a free-play interaction with their parent. Infants who scored low on contingent responsiveness during the free play task, also displayed fewer contingent smiles in the eye-tracking task. Moreover, both measures were found to have a common underlying factor. These results demonstrate that atypical social responsiveness observed in infant siblings is consistent across at least two contexts, suggesting the pervasiveness of the deviancies and highlighting the validity of both the gaze-contingent eye-tracking task and the free play task. This cross-context examination forms an important step to better understand the nature of observed difficulties in the first year of life. To consolidate these findings, replication in larger samples is essential, as well as investigation of social behaviour in different contexts, most notably the home environment. Research suggests that it cannot be assumed that parent-infant interactions in the lab are representative of interactions in the home environment (Belsky, 1980; Gardner, 2000).

To gain a full understanding of infant sibling development, it seems important to consider their behaviour in the context where they spent most of their time and where they gain the majority of their social experiences. Moreover, Elsabbagh & Johnson (2007) propose that cross-task examination is an important part of the examination of different developmental profiles leading to an ASD diagnosis. Future studies should endeavour to make empirical comparisons between social behaviour in infant siblings on multiple tasks and in differing circumstances so that the intricacies of the early development of ASD can be uncovered.

7.5. Implications for Development

The observed pervasiveness of reduced social responsiveness in both the gaze-contingent eye-tracking task and the free play task has potential implications for the further course of infant sibling development. The research conducted in this context thus far suggests that parents of infant siblings adopt different communication styles during interaction with their infants compared to parents of TD infants. Specifically, mothers of infant siblings display more directive behaviour during interaction compared to mothers of TD infants (Leezenbaum et al., 2014; Steiner et al., 2018; Wan et al., 2013; Yirmiya et al., 2006). Leezenbaum et al. (2014) posit that parental behaviour may be altered by the reduced social responsiveness observed in their infant. Similarly, Steiner et al. (2018) propose the directive communication style is an active attempt by parents to expand the range of play of their less engaged infant. Conceivably, when infants respond significantly less to socio-emotional, interactive input, the people in their social environment might start to adjust the frequency and quality of their own social utterances towards the infant. This could lead to a cascading effect, whereby infants receive increasingly less appropriate social stimulation, potentially negatively impacting on their subsequent social development. Although this suggestion seems plausible, it is complicated to tease apart the order of parental and infant behaviour. Due to the complexities of interaction it remains unclear if parents adjust their communication styles because of their infant's reduced engagement, or if infants' social responsiveness is affected by their parent's alternative communication style.

Wan et al. (2013) and Yirmiya et al. (2006) propose two other potential explanations to account for the relationship between infant behaviour and parental directiveness. Firstly, parents of infant siblings potentially adopt alternative communication styles because they are affected by the broader autism phenotype (BAP), often present in family members of individuals with ASD (Losh et al., 2008). Secondly, the communication style of parents of infant siblings might reflect their experience with their older child with ASD. In fact, research demonstrates that parents tend to show more directive behaviour in interactions with their older children with ASD (Crowell et al., 2019; Patterson et al., 2014), similar to interactions with infant siblings. Wan et al. (2013) note that the different explanations are not mutually exclusive, and more research is warranted to gain a better understanding of the intricacies of parent-infant interaction in families with children with ASD and infant siblings. Future research should gather data on the different factors that could impact on parent-infant interaction and examine to what extend each factor predicts characteristics of the interaction.

The importance of parental communication style for infant development was illustrated by the results from Chapter 5, which suggested that parental contingent responsiveness was positively related to infant social engagement. Although causal relationships could not be inferred from these data, parental contingent responsiveness has been identified as a key effective component of intervention for both infant siblings and older children with ASD (Green et al., 2017; Patterson et al., 2013; Shire et al., 2016). Furthermore, the data from Chapter 5 demonstrated that parental directiveness and parental contingent responsiveness were negatively related. This suggests that when parents engage in more directive behaviour, they are less likely to respond contingently to their infant, which could have a potential negative impact. In addition to the intervention studies, research with TD infants highlights the importance of contingent parental responsiveness (Ainsworth et al., 1974; Tamis-LeMonda et al., 2014), and thus a potential shortage of this behaviour could have a negative impact on infant development. The findings of Chapter 5 highlight the relationships between infant sibling and parent behaviour. It is important that parents of infant siblings receive adequate psychoeducation that is informed by such research findings, so that they can optimally support the development of their infant.

7.6. Next Steps

The findings of Chapter 3-5 of this thesis provide scope for further research in the area of the early development of ASD. A central notion to this thesis posed that the lack of sufficiently socially demanding and realistically interactive research methods is a potential reason that a reliable first-year marker for ASD remains elusive (Bussu et al., 2018; Keemink et al., 2019). The gaze-contingent face stimuli presented in this thesis were developed to take a step towards filling this gap in this important research area. The finding that the atypical behaviour observed in the interactive eye-tracking task extends to a real-life free-play task strengthens the argument for the use of the gaze-contingent paradigm within infant sibling research. The gaze-contingent eye-tracking paradigm seems particularly innovative and appealing in this context as it provides the ecological validity of a real-life interaction, whilst maintaining scientific rigour. For the progression of the field, it is essential that replication studies further establish the ability of this paradigm to detect ASD-symptomatic behaviour in the first year of life, most notably in larger infant sibling samples.

Moreover, to become truly beneficial to families with children ASD, it must be ensured that the proposed marker and the paradigm are transferable to clinical contexts. Szatmari et al. (2016) report that translation of potential endophenotypic markers found in research to a screening tool in clinical settings is not straightforward. There are several factors to consider, such as practical feasibility, staff training time and administration time. Researchers can take an important first step by translating their effect sizes from group differences into positive and negative predictive values of the proposed marker to make findings more generalizable to clinical contexts. When screening tools have been developed based on markers proposed by research, RCTs are required to evaluate the clinical benefit of the screening. These steps make up a lengthy process, and every small step counts, but it is important that researchers keep the translation to clinical application in mind in order to produce truly impactful research. Further research on the gaze-contingency paradigm should endeavour to include such positive and negative predictive values to gather more knowledge on the clinical utility of the paradigm.

One essential factor for results to become clinically relevant is the inclusion of outcome data that establishes which infants eventually receive an ASD diagnosis. A proposed first-year marker becomes more meaningful when follow-up data confirms whether the marker correctly predicted ASD outcome. The most prominent extension of the findings presented in this thesis is the inclusion of follow-up data. Although the findings of Chapter 3-5 provide promising data utilising a novel and uniquely interactive paradigm, the predictive value of the suggested measures can only be established when the tested infants are assessed in toddlerhood. The timeframe of a longitudinal study is challenging to pursue within the three years of a PhD, nevertheless, I had initiated the follow-up phase of the gaze-contingent experiments early 2020. I could have foreseen many obstacles along the way, but never had I expected a pandemic interfering with my research. Unfortunately, the planned extensive follow-up sessions had to be suspended, and I will not be able to collect this data within my PhD. However, is important to note that the inclusion of follow-up data is essential for the progression of the field, and researchers should endeavour to realise this. In their compelling 2018 article, Piven and colleagues highlight that one of the key challenges in infant sibling research moving forward is the inclusion of outcome data when infants are between 18 and 36 months of age. As the authors corroborate, it cannot be inferred if observed differences between infant siblings and TD infants are meaningfully related to a subsequent ASD diagnosis, unless infants are followed into toddler age. The data presented in Chapter 3 and 4 are still relevant and informative, as they provide foundations for future studies to build on. It is however important that the conclusions based on these data are drawn with caution.

Another challenge faced by researchers in the field of infant sibling research, is the issue of recruitment. Families with infant siblings are difficult to locate, especially when a lab is not situated in a large urban area. The studies including the most substantial participant samples are often part of large, international collaborations between universities and hospitals. Bölte et al. (2013), who reviewed the status of the infant sibling research field in Europe also note that in order to produce truly meaningful results in this research field, large-scale collaborations, networking and funding are required. However, it is important not to overlook the contributions of smaller labs; the larger the number of researchers involved in infant sibling research, the more progress the field can make. Furthermore, the advantage of data collected in one lab is the increased likelihood that variability in the way the data is collected remains relatively low. As an independently operating researcher, I was faced with the challenge of reaching a sample size large enough to produce meaningful results. This is an especially relevant issue in infant sibling research, as ASD represents a considerably heterogeneous spectrum, which should be accounted for in infant sibling participant samples (Piven et al., 2018). Moreover, research with infant siblings demonstrates that infant sibling development is also characterised by significant heterogeneity with at least four distinct developmental trajectories identified (Landa et al., 2012), which further warrants the inclusion of large sample sizes. Moving forward, although the contributions of smaller and larger labs should be taken into consideration to make optimal use of the available research, efforts should be made to form large scale collaborations to ensure sufficient power by accounting for the heterogeneity characteristic of the autistic spectrum.

In addition to ensuring that participant sample reach an adequate size, it is important that future research includes several comparison groups. The majority of studies focusses on comparing infant siblings to typical development; however, this is not sufficient to establish the utility of a potential endophenotypic marker. Inclusion of other risk samples (e.g., developmental delay, language delay, prematurity) is required to probe the specificity of a proposed marker (Zwaigenbaum et al., 2007). Furthermore, for the generalizability of findings it is essential that efforts are made to recruit diverse samples. In particular, factors such as ethnicity and socioeconomic status should be considered to ensure research findings can be accurately applied to the general population.

7.7. A First-Year Marker: Not Yet Found or Non-Existent?

In the introductory chapter of this thesis I proposed that the lack of success to date in revealing a first-year marker could be related to the inability of current methods to capture early ASD-related manifestations. Although the presented empirical findings provide tentative evidence for this hypothesis, alternative explanations should be considered. Due to the relative brain plasticity early in life allowing for effective intervention (Dawson, 2008), it would be highly beneficial to uncover reliable first-year markers to ASD, so that families can access appropriate care as early as possible to optimize later outcomes. However, it is important to critically evaluate whether it is realistic to believe that ASD is overtly detectable in the first year of life. Interestingly, a few studies suggest that on average parental concerns do not occur until the second year of life, varying from 14 to 19 months of age (Chawarska et al., 2007; De Giacomo & Fombonne, 1998), although a study by Young, Brewer and Pattison (2003) found that a third of parents in their sample (N=153) reported concerns from birth.

Elsabbagh and Johnson (2007) suggest some explanations for the subtle presentation of differences between TD infants and infant siblings in the first year of life. Firstly, the authors propose that the core deficit pertaining to ASD might be specific to abilities that do only emerge later in childhood, causing impairments to be observable not until after the first year of life. Furthermore, the presentation of symptoms is likely to change significantly over time, and as a consequence observed subtle differences in infancy may be dissimilar to manifestations at time of diagnosis (Gillberg et al., 1990; Zwaigenbaum et al., 2015). However, the single core deficit theories are heavily debated, as described in introductory Chapter 2, especially considering the striking phenotypic heterogeneity inherent to the autistic spectrum. The single core deficit theories are unable to account for all the symptoms that are part of an ASD diagnosis and converging research evidence suggests a gradual onset of symptoms in several domains (Happé, Ronald & Plomin, 2006; Pellicano et al., 2006). Therefore, Elsabbagh and Johnson (2007) propose it may be most plausible to view ASD as the sum of multiple risk factors in interaction. Certain early deviancies, such as reduced social responsiveness may be necessary but not sufficient for autism to emerge (See Elsabbagh & Johnson, 2007). This notion provides challenges for researchers, as it implies each diagnosed child may have had an individual pathway to diagnosis consisting of multiple interacting factors contributing to unique extents. Mapping out these pathways and uncovering any potential similarities between individuals will require rigorous following of infant siblings from the day they are born. Similarly, Szatmari et al. (2016) recommend future research to focus on the development of different behaviours over time, rather than assessing specific markers at different ages. This does not imply that the findings gathered in this field thus far are redundant. These previous studies were necessary to reach this conclusion and they provide essential foundations for future research to build on.

Secondly and related to the aforementioned, Elsabbagh and Johnson (2007) suggest that the unresolved first-year puzzle may be attributable to the finding that not all infants follow the same pathway to diagnosis. For instance, Landa et al. (2012) demonstrated that in a large infant sibling cohort distinct subgroups can be identified. Studies making group comparisons may therefore fail to detect early manifestations of ASD, which relates back to the argument for the distribution-based approach presented in Chapter 3 and 4 of this thesis.

Taken together, it remains unclear whether ASD can be reliably detected in the first year of life. The findings derived from the gaze-contingency paradigm are promising, but replication and outcome data are essential next steps. Although neurophysiological research suggests early deviancies in brain responses towards social stimuli (Elsabbagh et al., 2009; Elsabbagh et al., 2012; Key et al., 2015; Lloyd-Fox et al., 2013; Orekhova et al., 2014), the absence of overt behavioural symptoms in the first year remains an option. Future research should endeavour to prioritize developmental trajectories and implement analysis approaches that account for individual differences to address these questions. Scrutinizing individual trajectories will also inform the field about protective factors, which can be foundational for preventative and supportive care.

7.8. Social Understanding

The final chapter of this thesis took a step away from the research on infants' active involvement in a social interaction and explored what infants' observations of everyday interactions reflects about their understanding of basic conversational principles. Infants do not only refine their social skills by actively participating in a social interaction, but also by frequently observing everyday interactions around them, which likely serve as a model for their understanding of how social interactions are typically performed. Previous studies in this research area demonstrated that infants are sensitive to variations from typical interaction such as back-to-back conversations (Augusti et al., 2010), incongruent use of emotions and affect (Biro et al., 2014; Choi

& Luo, 2015), and infant-directed speech directed at adults (Soley & Sebastian-Galles, 2020). The study presented in Chapter 6 examined a novel element of conversations not previously studied, namely the knowledge 6- to 12-month-olds infants hold about what constitutes a realistic interaction partner. This study also included a substantially larger sample and novel stimuli relative to previous research. To investigate this understanding, eye-tracking data was collected whilst infants viewed cartoons in which two characters held an everyday conversation. Characters were either animate (human) or inanimate (object) to explore if infants' fixations and gaze shifts would reflect how much they know about what a realistic interaction entails. The findings showed that infants' fixations and eye movement patterns are substantially different depending on the animacy of the characters engaged in conversation, suggesting that infants assign social communicative signals to human characters more strongly than to object characters. These results aligned with earlier findings on early social attention and understanding of animacy in the first year of life (Ellsworth et al., 1993; Frank et al., 2009; Johnson et al., 1991; Luo et al., 2009; Rakison & Poulin-Dubois, 2011; Southgate et al., 2008).

Considered together with the findings from the gaze-contingent experiments discussed in Chapter 3 and 4, in which it became evident that infants respond to reciprocity when they are an active participant in an interaction, the findings of this thesis suggest that 6- to 12-month-old infants are sensitive to levels of reciprocity within interaction both as an active participant and as a passive observer of human social interaction. Moving forward it would be interesting to include a sample of infant siblings for the Chapter 6 study presenting infants with cartoons of human and object characters. This thesis included infant siblings only in Chapter 3-5, as it focussed on the active participation of the infant siblings to create a more socially demanding experience. Previous research probing differences in social attention between infant siblings and TD infants using passive viewing paradigms have produced mixed results (Chawarska et al., 2013; Key & Stone, 2012; Kleberg et al., 2018; Shic et al., 2014). It is therefore unclear whether the cartoon method from Chapter 6 would be suitable for infant sibling research. However, the clear findings derived from a TD sample provide a good foundation for comparison that might be worth pursuing.

7.9. Improving Methodologies

This thesis aimed to extend previous research on infant social development by presenting novel research paradigms to investigate social development in TD infants and infant siblings of children with ASD. For studies focussing exclusively on typical development, the use of inadequate stimuli means that the extent to which they produce findings that generalize to 'real world' social interactions is unclear. For the line of research involving infant siblings, these methodological issues have resulted in an ambiguous pattern of results. The first three experimental chapters (3-5) focussed on methodologies used in research attempting to uncover early behavioural manifestations of ASD. A novel, uniquely interactive method, the gaze-contingency paradigm was introduced, as a response to the inability of current methods to capture ASD-related social symptoms at an early age (Bussu et al., 2018), despite the fact that neurological research consistently confirms deviancies in neurological responses towards faces and social scenes in 4- to 14-month-old infant siblings later diagnosed with ASD (Elsabbagh et al., 2009; Elsabbagh et al., 2012; Key et al., 2015; Lloyd-Fox et al., 2013; Orekhova et al., 2014). It was argued that the methods behavioural eye-tracking studies have employed to date are lacking in their ability to detect early social deviancies due to oversight of the contingency and reciprocity intrinsic to social interaction. By contrast, the gaze-contingency paradigm does include the experience and measures of contingency and reciprocity. The two experimental studies employing the gaze-contingency paradigm (Chapter 3 & 4) demonstrated its efficiency in an infant sample. The paradigm succeeded in providing an interactive experience and infants were actively engaged in the task. Furthermore, video-recorded behavioural responses seemed best suitable to detect subtle differences in social behaviour between TD infants and infant siblings. The validity of the method was further established in Chapter 5, in which findings derived from the gaze-contingent stimuli were successfully related to infant behaviour during a face-to-face play interaction between parent and infant. The empirical cross-validation of research methods is of vital importance for the progression of the field (Gangi et al., 2018; Risko et al., 2012). Similar to Chapters 3 and 4, the final experimental chapter (Chapter 6) aimed to advance earlier studies focussing on social understanding of observed third-party interactions in typical development by employing novel stimuli that more closely approximate real-life social interaction. Previous research on infant social understanding had predominantly used animated shapes as acting agents within a social interaction (Biro et al., 2014; Hamlin et al., 2007; Mascaro & Csibra, 2012; Soley & Sebastian-Galles; Thomsen et al., 2011) and it is questionable whether such shapes are representative of the interactions that infants observe in day to day life. To address this issue, Chapter 6 employed animated cartoon characters as stimuli that looked more realistically human, and the findings suggested 6- to 12-month-old infants have an understanding of basic conversational principles.

The experimental studies presented in this thesis endeavoured and succeeded to improve methods used in previous research and aimed to develop paradigms that more closely approximate the real-world context infants experience on a day to day basis. The use of these novel, enhanced stimuli produced important and informative findings, foundational for future studies. However, these methods do not perfectly correspond with social experiences in the real world and lack realism to a certain extent. For instance, research suggests that behaviour in eye-tracking studies is not always comparable to behaviour in face-to-face studies (Risko et al., 2012; Schmitow & Stenberg, 2015). Nevertheless, the use of animated characters and video-recorded persons rather than real humans allows researchers to have greater control over the stimulus presentation. For future research, it is essential that the implications of the type of stimulus researchers select is carefully considered and that methods are improved accordingly. Research conducted with the aim of informing real life processes as best as possible will be most impactful, and therefore larger studies comparing the effect of several different methods on infant responses are required. This thesis offered important improvements to previous methods on which future studies can build, and technological advancements will enable further progression to optimise infant research methods.

7.10. Conclusion

In sum, this thesis introduced novel research methods for the examination of social development in both TD infants and infants at elevated familial risk for ASD. The use of novel gaze-contingent face stimuli was tested in a TD sample, and subsequently provided promising abilities to detect prodromal symptoms of ASD. Findings from the gaze-contingency paradigm were contrasted with results from a free play task, providing further evidence for the efficacy of the paradigm. The last experimental chapter demonstrated infants' understanding of what constitutes a realistic human conversation using novel stimuli.

Together, the experimental chapters suggest that to a certain extent 6- to 12-month-old infants understand and respond to socio-communicative intent both as an active participant and as a passive observer of human social interaction. Furthermore, the novel stimuli and paradigms employed in this thesis provide scope for further research in the area of typical and atypical development. The findings highlight that researchers are faced with the challenge of finding the fine balance between ensuring methods are as realistic and naturalistic as possible, whilst simultaneously maintaining scientific rigour. With the ongoing effort from new and established researchers in the field, the knowledge on the typical and atypical social development will continue to progress, and this thesis provides a small, yet significant step towards the advanced understanding of typical and atypical social development in the first year of life.

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