SEX DIFFERENCES IN THE DEVELOPMENT OF VISUAL PROCESSING IN INFANCY

by

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Abstract

The first months of life are a sensitive period for the development of visual processing, and face processing in particular. The main goal of this thesis is to examine the influence of infant sex on the development of visual processing. The overarching hypothesis was that 5-month-olds would differ in performance on tasks related to the higher levels of the ventral processing stream, with females showing more advanced ventral visual processing. To begin tracing the developmental trajectory of these differences, another group was tested at 7 to 8 months, after major changes in face processing abilities occur. An exploratory look was taken throughout at two factors that may influence face processing development – the size of the social environment, and locomotion level.

In Chapter 2, 5-month-olds were tested on detection of an eye expression change, from smiling to neutral, following infant-controlled habituation. As predicted, females outperformed males in evidencing a novelty preference. In Chapter 3, 7- to 8-month-olds were tested on the same task. For females, a developmental change from novelty to familiarity preference was found. For males no indication of eye expression discrimination at either age was found. In Chapter 4, both age groups were tested on discriminating a featural change in internal features (eyes, nose, mouth). A female advantage was found in 5-month-olds, but disappeared by 7 to 8 months. Chapter 5 replicated the Chapter 2 findings of female superiority in eye expression discrimination at 5 months. Contrary to prediction, females did not show greater mirror image confusion. Laterality effects for both eye expression and mirror image discrimination were found in females, and a negative relation between mirror image and eye expression discrimination was found in males. Finally, effects of the social environment on male face processing and of locomotion level on female face processing were found.

The results support the hypothesis of a sex difference in the development of ventral stream processing. They inform the fields of visual/face processing development and of sex differences, showing a sex difference in infant development of processing of internal facial features and identifying additional factors involved, and have implications for studies of autism.

Preface

The ideas presented in this thesis represent the work of the author, developed in discussion with her PhD advisor, Dr. J. Werker.

For all studies in this thesis, hypothesis generation, study design, data analysis, interpretation of results, and manuscript preparation were completed by the author in consultation with and under the supervision of Dr. J. Werker. Data collection for the studies in chapters 2 through 4 was completed primarily by the author, with data for the remaining subjects collected by F. Brough, J. Barclay, and A. Budd. Data for the studies in chapter 5 was collected by the author, F. Brough, J. Barclay, and A. Budd. Participants in all studies in the thesis were recruited by the Infant Studies Centre and the Early Development Research Group. Ethics approval for all studies in the thesis was provided by the UBC Behavioural Research Ethics Board, UBC Ethics certificate number H95-80025, Project Title: Linking Speech Perception to Language Acquisition: Biases, Mechanisms and Products.

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1 Introduction

1.1 General overview

During the first few months of life, an infant is extremely limited in the ability to explore objects, due to limited capacity for self-generated motion, poor manual skills, and immature perceptual abilities. Thus much of what is learned in these first few months stems from interaction with caretakers and other people when they are in close proximity to the infant. What an infant learns and processes in the first months of life, as the brain is developing, forms a foundation for later learning. In some cases, for example infants with untreated cataracts (Lewis & Maurer, 2005), sensitive periods have been identified in which the lack of patterned visual input has long-term consequences for brain development and visual function. Among other visual processing abilities, this early period has been found to be important for the development of face processing. For instance, infants with unilateral left eye or bilateral cataracts were found to be impaired in face processing years later, even when the cataracts were removed as early as 2 or 3 months of age (Le Grand, Mondloch, Maurer, & Brent,2003; Le Grand, Mondloch, Maurer, & Brent, 2004). Yet even infants with no deficit in their sensory organs may differ in what they attend to, process and learn in the early months, and that could have consequences on later processing. The focus of this thesis is to examine one factor that may influence the development of visual processing in this early period and beyond – the factor of infant sex.

Sex differences in attention to, response to, and processing of stimuli have repeatedly been reported. In illustration, females have been found to maintain eye contact longer in conversational interactions (Levine & Sutton-Smith, 1973), to be better at face recognition than males (Herlitz & Lovén, 2013), and to be better at facial expression processing than males (McClure, 2000). Elucidating the pattern of differences of visual processing and visual attention between the sexes during infant development may shed light on the process by which individual social and visual processing developmental trajectories diverge. If, as I suggest (see below), males and females emerge from this initial period with different visual processing sensitivities and attend differently to their environment, and to faces in particular, this could lead to a gap in the foundation of their social development that may widen over the years. If the same pattern of differences in development is exaggerated in autism, as would be predicted by a developmental interpretation of the 'extreme male hypothesis' (for hypothesis, see Baron-Cohen, 2002), initial differences in visual processing could contribute to the pathway that leads to the full-blown disorder. Thus, in addition to improving our knowledge of infant social and visual processing development in general, research on early sex differences in visual processing and face processing could ultimately contribute to a better understanding of autism and to better treatments.

The studies in this thesis examined differences in visual processing between male and female infants towards the end of this early period, in which interaction with objects and self-generated locomotion has been minimal, but faces have frequently been encountered in close proximity (see section 1.2) – at 5 months (early infancy), as well as in a later period, when object manipulation and locomotion are more developed, and considerable advances in face processing have occurred – ages 7-8 months (later infancy). Following a careful review of the literature (see below), I hypothesize that females emerge from this first period more advanced in the development of the ventral visual stream or with a greater tendency to use the ventral visual stream for visual processing than males (see McGivern, Adams, Handa, & Pineda, 2012; Handa & McGivern, 2015, for a similar approach to explaining cognitive sex differences in adults, and see Alexander, 2003 for a suggestion of innate, evolved, sex differences in visual processing biases, with a male bias for dorsal stream processing, and a female bias for ventral stream processing). In particular, I hypothesize that females aged 5 months, in comparison to same aged males, will be better able to detect featural changes in eye expression and in internal facial features, alongside poorer ability to distinguish between a familiar object and its mirror image. As there is much evidence for developmental changes in face processing between the ages of 5 months and 7-8 months, face processing was also tested in the later period. The studies in this thesis have been designed to compare the performance of female and male infants in certain tasks that can be performed by the higher levels of ventral stream processing, with the hypothesis that female performance will be in the direction of more developed ventral processing relative to males. The studies were not designed to show, nor do I claim, that visual processing development between the sexes differs only in terms of ventral stream processing, and in particular no claim is made with respect to sex differences in the development of dorsal stream processing.

As will be reviewed below, the gender and race of the faces that infants experience have been shown to affect the development of face processing biases and discriminative sensitivities (e.g. Kelly et al., 2009; Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). To control for this potential confound, the infants' mothers contacted for all of my studies were selected to be of the same ethnic appearance as the face stimuli used in the study (i.e. Caucasian). Recent research using head mounted cameras has documented sizeable differences in the richness of the social environment encountered by different infants (e.g. Sugden, Mohamed-Ali, & Moulson, 2014), but the emerging knowledge of such documented variation has not yet been systematically used to inform experimental studies. As a first step toward recognizing how sources of variation in social experience might contribute to the development of face processing, the studies in this thesis also took an exploratory look at the influence of the size of the infant's social environment on his or her face processing abilities. If the underlying cause for the difference in face processing development between the sexes is that one sex, e.g. males, has a tendency to look less at faces or eyes, this may lead to less developed face processing abilities than a female in an identical environment. However, a male reared in a rich social environment, with a variety of people interacting with him throughout the day, may develop face processing skills identical to or even surpassing those of a female raised in a relatively impoverished social environment. Finally, as head mounted eye tracker studies have also recently shown, locomotion development dramatically changes the visual input an infant receives (Kretch, Franchak, & Adolph, 2014; see below). Thus an exploratory look was also taken at the relation between the development of locomotion and face processing abilities in both of the infancy periods studied in this thesis.

The research questions I explored in this thesis are:

1. Are there sex differences in infancy in visual processing in tasks that can be performed by the higher levels of the ventral stream?

2. What is the trajectory of these differences across development?

In the following sections, I will review the evidence that led me to the hypothesis of a more developed ventral visual stream in infant females in early infancy, as well as to particular properties of the ventral stream I propose are more developed in infant females in this early period. Research related to two properties I hypothesize differentiate between males and females at the end of the early period will be presented – the distinction between an object and its mirror image, and face processing, in particular the processing of facial features and of featural changes in eye expression.

1.2 Visual input in the first year of life and the development of face processing

The first months of life seem ideal for initial development of face processing, since during these months, as mentioned above, an infant is extremely limited in the ability to explore other stimuli, such as objects, unable to approach or manipulate them. Faces, on the other hand, are frequently encountered by the infant, at a near distance that is optimal in terms of visual acuity of the infant (see Jayaraman, Fausey, & Smith, 2015). Recent studies, using head-mounted cameras to track the visual input available to infants, have found that during the first 3 or 4 months of life, infants spend 25% of their time exposed to faces (Sugden et al., 2014; Jayaraman et al., 2015). In addition, the majority of these faces are within 2 feet of the infant. The proportion of faces encountered decreases with age during the first year of life, and the distance of the faces from the child increases (Jayaraman et al., 2015). With age, although people are still in view in about 25% of the scenes recorded by head mounted cameras worn by infants, there is a shift from a visual environment dense with faces to a visual environment dense with hands acting on objects (Fausey, Jayaraman, & Smith, 2016). Visual input during these first few months has a profound effect on the development of face processing, as evidenced by studies of infants with cataracts, as mentioned above (Le Grand et al., 2003; Le Grand et al., 2004). Thus, adequate visual input during the first year of life, and the first half year of life in particular, is important for the development of face processing.

Sex differences have been found in face processing (e.g. Rehnman & Herlitz, 2007; McBain, Norton, & Chen, 2009; Sommer, Hildebrandt, Kunina-Habenicht, Schacht, &Wilhelm, 2013), and deficits in face processing are also found in autism (e.g. Weigelt, Koldewyn, & Kanwisher, 2012). Looking at the early infancy period could provide clues about how these sex differences develop, how early they manifest, and what factors could influence their appearance. One possibility is that differences in the way male and female infants attend to their environment, with females attending more than males to faces in their environment and to the eyes within a face, lead to more advanced development of face processing and of the ventral visual stream in females. However, any sex differences in attention to faces and to eyes within a face may be driven by earlier or lower-level differences in ventral visual stream processing (see

Alexander, 2003). This thesis does not attempt to tease apart these two options, but only explores whether indeed infants of the two sexes differ in visual perception tasks tied to ventral visual stream processing, and in face processing in particular, in the two ages. If such differences are found, future studies could then look at the relation between the infants' looking behavior and face processing development, and at factors influencing the infants' looking behavior (e.g. the females' preference for faces and eyes compared to the males). The two visual streams will be described in section 1.3.

In addition to the effect of deprivation on face processing in these months, the specific faces experienced by the infant have also been shown to shape the infant's face preference and face processing sensitivities. Neonates prefer to look at their mother's face over a stranger's face (e.g. Bushnell, Sai, & Mullin, 1989). Three-month-olds prefer to look at females, when a female is their primary caretaker, but tend to prefer males when a male is their primary caretaker, and infants with a female primary caretaker also display recognition memory for individual females but not males (Quinn et al., 2002). Three-month-olds also prefer to look at faces of people of the same ethnicity as their caretaker (e.g. Bar-Haim, Ziv, Lamy, & Hodes, 2006; Kelly et al., 2005; Kelly et al. 2007) and have been found to be able to discriminate between two faces of their own race better than between two faces of another race (Sangrigoli & de Schonen, 2004). In their head-mounted camera study, Sugden et al. (2014), beyond finding that faces occupy the visual field of the infant 25% of the time, also found that the faces experienced by young infants (with a female primary caretaker) were mostly female (70%), own-race (96%), and adult age (81%), with similar findings of faces experienced during the first year obtained in a study using parental questionnaires instead of head-mounted cameras (Rennels & Simmons, 2008). This suggests that by 3 months, the faces experienced by the infant are already shaping the infant's preference and face processing abilities. These findings also raise the possibility that individual differences in the social environment of the infant will influence the infant's preferences and shape the infant's face processing ability, with infants with a larger pool of familiar faces better able to discriminate between faces. Indeed, a recent study (Balas & Saville, 2015) points to the size of the social environment experienced during childhood shaping face processing abilities. The study found face memory and ERP responses to faces were related to the size of the community in which a student had grown up, with better face memory performance evidenced by students from larger communities.

Head-mounted eye trackers have revealed that locomotion also affects the visual input available to the infant (Kretch et al., 2014), with crawling infants, for instance, seeing faces less than walking infants, even though the task in the study biased the infants to look at the face of the caregiver. The visual input of crawlers changed when they sat up, at which time the caregiver's face came much more often into view. This suggests locomotion, as well as the ability to sit, have a profound effect on face experience, which perhaps leads to effects on face processing. Recent studies have found this is indeed the case for sitting ability (e.g. Cashon, Ha, Allen, & Barna, 2013). Libertus and Needham (2014) looked at motor activity, of which locomotion is a factor, and found lower motor activity at 3 months correlates with higher preference for a face over a toy. This finding did not hold for 5- to 11-month-old infants, and the authors suggested this is due to reduced variability in infants' preference scores and motor activity scores. However, since my study looks at face processing, and not face preference, a greater preference for faces at 3 or 4 months may result in better face processing capabilities at 5 months. Due to their hypothesized effects on face processing, the factors of size of social environment and level of locomotion were explored in all studies in this thesis. My hypothesis throughout was that a lower level of locomotion and a larger social environment will be related to better face processing, for either or both sexes.

1.3 The dorsal and ventral visual streams

There is substantial evidence pointing to two visual processing streams, specialized for different types of processing – the dorsal and ventral visual streams (Ungerleider & Haxby, 1994; Goodale & Milner, 1992; see review in Johnson, Mareschal, & Csibra, 2001). In the macaque, the two visual streams were identified by Ungerleider and Mishkin (1982). The ventral route, or the "what" route, was proposed to be related to object identification (Ungerleider & Haxby, 1994). It extends from the primary visual cortex through to the temporal cortex, ending in the inferior temporal cortex. It analyzes the visual scene in detail and more slowly than the dorsal stream (Johnson et al., 2001). It processes color, shape, and other surface properties of objects, such as texture (Livingstone & Hubel, 1988). The occipitoparietal dorsal route, or the "where" route, which extends from the primary visual cortex to the parietal cortex, deals with the spatial organization of objects – it processes direction of motion and velocity, and analyzes the spatial relations between objects and their locations in space (Livingstone & Hubel, 1988;

Ungerleider & Haxby, 1994). Goodale and Milner (1992) suggested a somewhat different distinction between the streams – that the ventral route is the perception pathway, while the dorsal stream is the action, or “how”, pathway, mediating the required sensorimotor transformation (sensory information to motor coordinates) for visually guided actions on objects (Goodale & Milner, 1992). In addition to location and motion, the dorsal stream processes size, coarse shape and orientation (Jeannerod, 1988; Murata, Gallese, Luppino, Kaseda, & Sakata, 2000).

Areas in both streams are organized hierarchically, where neuronal response properties further along the stream become increasingly complex (Ungerleider & Haxby, 1994). In the ventral stream, this includes face recognition cells in the fusiform face area (see Kanwisher & Yovel, 2006). Certain areas of the dorsal stream are sensitive to global motion, rotation, or motion in depth (Ungerleider & Haxby, 1994).

One particular property of the final stages of the ventral processing pathway is a lack of sensitivity to mirror images, i.e. a unification of an object and its (left-right) mirror image. In adult macaques, inferotemporal lesions disrupt the ability to distinguish between two different 2D shapes, but facilitate discrimination between a shape and its mirror image (Walsh & Butler, 1996). This phenomenon, of a dissociation between the ability to identify objects and the ability to distinguish between an object and its mirror image, has also been found in neuropsychological studies in humans (e.g. Davidoff & Warrington, 1999, Warrington & Davidoff, 2000). In one study (Warrington & Davidoff, 2000), a patient’s ability to discriminate between mirror image rotations was dependent on her inability to identify the object. This suggests that processing in late stages of the ventral stream unites an object and its mirror image (see Davidoff & Warrington, 2001). Indeed, in fMRI studies (e.g. Dilks, Julian, Kubilius, Spelke, & Kanwisher, 2011) it was shown that later stages in the object processing hierarchy are not sensitive to mirror image distinctions. Both 3- to 4-month-old infants (Bornstein, Gross, & Wolf, 1978) and children (e.g. Cronin, 1967) have been found to be susceptible to mirror-image confusion, presumably through the same mechanism of a ventral stream unification of an object and its mirror image. Thus, infants who have a less developed ventral visual system, who process more slowly, or do not process the object fully through the ventral stream, are expected to outperform infants who are faster/better ventral processors or infants who tend to process with the ventral stream, in tasks that require distinguishing between a familiarized object and its mirror image. In the next section I will present research evidence that points to the possibility of a sex difference in infancy in mirror image discrimination, in line with a difference in the rate of development of the ventral stream.

Another extensively studied task performed by the ventral stream is face processing. An influential model of face processing (Haxby, Hoffman, & Gobbini, 2000) places the core elements of the face processing system in the occipitotemporal regions, with the face-responsive area in the fusiform gyrus mediating the representation of the invariant aspects of the face (such as face identity), while representation of the changeable aspects of the face (such as eye gaze, lip movements, and facial expression) is mediated by the superior temporal sulcus, at the intersection between the dorsal and ventral streams, with the occipital face area in the inferior occipital gyrus providing input to both the fusiform face area and the superior temporal sulcus. In recent years this division to invariant vs. changeable aspects of the face has been questioned, as considerable evidence has accumulated to suggest the fusiform gyrus is involved in facial expression processing as well (e.g. Fox, Moon, Iaria, & Barton, 2009; Achaibou, Loth, & Bishop, 2016). As a specific example, successful detection of changes in face stimuli is associated with increased activity in the fusiform face area when either a change in identity or a change in facial expression is detected (Achaibou et al., 2016). This has prompted the development of new models, such as a model that posits the superior temporal sulcus is part of a dorsal face processing stream concerned with motion (in this case of the face), while the fusiform face area is part of a ventral face processing stream concerned with form (Bernstein & Yovel, 2015), including the form of the facial features in static expressions of emotion.

In this thesis, in addition to testing mirror image discrimination, I chose to focus on face processing, in this case detection of changes in the face, as an indicator of higher level processing in the ventral stream. This choice is due to several reasons. First of all, if sex differences in attention to eyes within a face and to faces in competition with other stimuli (see next section) are driving the differences in ventral visual stream processing development, it is plausible that differences in face processing will be prominent, with differences in other domains secondary and perhaps later developing compared to differences in face processing. Second, since face processing development in infancy has also been extensively studied, there is also some initial evidence that points to a female advantage in face processing in infancy, especially of a face in the canonical forward facing position (see next section). However, the nature of this female advantage has not been extensively studied. In this thesis I chose to focus on differences in the development of the processing of facial features, rather than facial configuration (e.g. the second order relations, in terms of the relative location of the features in the face – see Maurer et al., 2002), even though holistic processing – i.e. processing of the face, with the features in their configuration, as a gestalt, is considered a hallmark of expertise in face processing. The reason I chose to focus on features in this thesis is that differences in performance in a task measuring the ability to detect a change in facial features are more likely to reflect differences in ventral stream processing than differences in dorsal stream processing. Although the ventral stream processes facial configuration as well, a change in facial configuration can also be described in terms of tracking of a change in the locations of objects (the facial features) in space, while fine differences in facial features are not likely to be processed by the dorsal stream. This is also the reason that the main discrimination tasks in the thesis involve a long inter-trial interval (at least 2 seconds) and an intervening stimulus – to reduce the likelihood of perceiving a dynamic change and processing the change through the dorsal stream. Thus, individual and sex differences in performance of these tasks are likely to reflect differences in ventral stream processing, and not differences in dorsal stream processing, and it is unlikely that infants using different strategies (i.e. some using only the dorsal stream, and some using the ventral stream) will exhibit an equal level of performance.

As shown in the next section, there is indeed evidence to suggest that females may process facial features better than males in infancy. Due to the importance of eye expression processing for social interaction and social development, one of the featural changes I focused on was a featural change in eye expression. Only the eye features were changed, and not the eye brows (in which changes frequently include changes of orientation and/or of configuration in terms of the distance between the eye brows and the eyes and the other internal features of the face, and between the eye brows and the frame of the face), and the location of the features was not changed – again to minimize the likelihood of the changes being processed directly though the dorsal stream. Below, I review the current evidence for sex differences in ventral visual processing, as well as evidence for sex differences in attention to eyes within a face and to faces compared to other stimuli in the environment, which may be related to differences in ventral visual stream development – either because they are driving ventral visual stream development by providing relevant input, or because they are driven by initial sex differences in ventral visual stream development, or both.

1.4 Sex differences in ventral stream visual processing, including mirror image discrimination and face processing

Sex differences in early infancy, as well as in adulthood, have been found in several tasks of visual processing. In the present section I will review evidence that older infant males and females, in the second year of life, differ in their capability of or tendency for processing in the later stages of the ventral stream, and then turn to data that suggests younger male and female infants, in the first year of life, may differ on several properties related to visual processing in the ventral stream – the ability to distinguish between an object and its mirror image, and face processing, including some data relevant to the processing of eye expression and of facial features.

Evidence for more advanced ventral stream capabilities in infant females at an older age range (15 to 30 months) has been found using a concurrent discrimination task, in which discrimination between several pairs of objects has to be learned simultaneously (Overman, Bachevalier, Schuhmann, & Ryan, 1996). The same female advantage has been found in 3-month-old infant rhesus macaques (Bachevalier, Hagger, & Bercu, 1989), and is reversed following hormonal manipulations – e.g. neonatally orchiectomized infant males perform as well as females in concurrent discrimination (Hagger & Bachevalier, 1991). Furthermore, neonatal ablations of area TE in the inferior temporal cortex in the macaques impair performance in concurrent discrimination in infant females, but not in infant males (Bachevalier, Brickson, Hagger, & Mishkin, 1990). This suggests the infant females either tend to use the inferior temporal cortex in tasks in which males do not, or that their inferior temporal cortex processing capabilities are more developed or operate more quickly than those of males. This thesis aims to find whether more advanced ventral stream capabilities in human infant females compared to males are already evident at the age of 5 months. In the current thesis, two aspects of ventral visual stream processing for which there is some evidence in infancy will be studied – the unification of an object and its mirror image, and face processing. The focus in my thesis and in the design of the experiments is on processing differences in later stages of the ventral stream, not on the potential contribution to this processing from earlier stages in the ventral processing stream. I now turn to previous research which suggests there may indeed be sex differences in the performance of tasks related to mirror image discrimination and face processing in infancy.

1.4.1 Mental rotation or mirror image discrimination?

One specific area in which sex differences have often been found is mental rotation (Voyer, Voyer, & Bryden, 1995), with males showing superior performance. Four studies have shown similar differences between male and female infants, including in the pre-mobile, pre-object manipulation period (what I call “early infancy”). Three- to four-month-old males familiarized with a 2D shape (figure 1 or its mirror image) in different rotated orientations showed a novelty preference for the mirror image of the shape, while females did not show any preference (Quinn & Liben, 2008), with a follow-up study finding the same sex difference in six- to seven-month-olds as well as in nine- to ten-month-olds (Quinn & Liben, 2014). Five-month-old males habituated to a 3D figure rotating in a certain angle preferred to look at the mirror image of the figure rotating in the complementary, unseen, angle vs. the original figure rotating in the same unseen angle, while females did not (Moore & Johnson, 2008), with a follow up study finding a familiarity preference in younger, 3-month-old, males, but again no preference in females (Moore & Johnson, 2011).

However, as reviewed in section 1.3, the ability to distinguish between an object and its mirror image is eliminated in late stages of the ventral visual stream. It is possible that the results of the mental rotation studies in young infants described above are not related to mental rotation, but to the ability to distinguish between an object and its mirror image – since all the infant studies mentioned above required the ability to respond differentially to the image that had been presented in familiarization and to its mirror image.

There is prior evidence for mirror image confusion in infants by the age of three to four months, when face profiles or simple line shapes are used as stimuli (Bornstein et al., 1978) – however, there is no mention of analysis by sex in that study. At least one study in adults (van Strien & Bouma, 1990) has found no difference in the ability of males and females to rotate images, but a difference in mirror image discrimination. Females were slower to respond when discriminating between a 2D shape and its mirror image, when the mirror image was presented to the right hemisphere (left visual field). A sex difference in mirror image discrimination has also been found in children in kindergarten and first grade (Cronin, 1967), with males outperforming females. Thus, since mirror image confusion is already present in young infants, familiarizing infants with a non-rotating object may elicit sex differences in the ability to distinguish between the object and its mirror image similar to those found in the mental rotation studies, with females failing to distinguish between the images, and males succeeding. Testing infants on such a task of mirror image discrimination that does not involve mental rotation, in addition to providing data regarding the hypothesis of a more developed ventral visual stream in females, would also be an important step in elucidating when in development the sex difference in mental rotation arises, and whether it is indeed present already in early infancy, or whether, for instance, the development of a sex difference in mental rotation requires considerable experience with object manipulation.

1.4.2 Sex differences in attention to eyes and faces and in face processing in infancy

Another area in which sex differences have often been found is attention and response to eyes and to faces in canonical, full-frontal view. This difference is evident from early infancy. Females show a greater tendency to maintain eye-contact in live interactions, starting from early infancy (e.g. newborns, Hittelman & Dickes, 1979; 3-month-olds, Leeb & Rejskind, 2004). In terms of attention to faces, one study (Connellan, Baron-Cohen, Wheelwright, Batki, & Ahluwalia, 2000) presented neonates sequentially with a naturally moving live, silent smiling female face and a constantly moving 3D mobile of this face scrambled. This study revealed a significant association between sex and stimulus preference such that, while more neonate males than would be expected by chance looked for a longer proportion of the time at the mobile than at the face, fewer female newborns preferred the mobile than would be expected by chance. A similar pattern was found at 12 months – when shown silent videos sequentially, males preferred to watch a video of mechanical motion (cars racing or windshield wipers) over one or two people talking, while females showed the opposite pattern (Lutchmaya & Baron-Cohen, 2002). When static stimuli such as checkerboards and bullseyes, were presented sequentially with static face stimuli, in one study (Lewis, Kagan, & Kalafat, 1966) it was found that 6-month-old females directed longer first looks to the face stimuli, while the first looks of males to the various stimuli did not differ in duration. When static images of objects and faces were presented simultaneously, Gluckman and Johnson (2013) found 6-month-old females looked at faces for longer durations than males. Taken together, these studies indicate male and female infants differ in their attention and response to faces and eyes, such that females have a stronger preference for faces, respond more to faces than to other stimuli, and maintain eye contact longer than males in interactions.

A recent eye-tracking study has also revealed a sex difference in scanning patterns of faces, starting from early infancy (3 to 4 months) and continuing to adulthood: females make more fixation shifts between internal features of the face (eyes, nose, mouth), while males make more shifts between internal and external features (hair, forehead, chin, ears) (Rennels & Cummings, 2013). In a study looking at adults performing facial expression recognition tasks, it was found that females are better than males at facial expression recognition, that females look more at the eyes than males, and that facial expression recognition correlates with looking to the eyes (Hall, Hutton, & Morgan, 2010). In addition, when only the eye area is presented, adult females have been found to be better than males at recognition of emotions from the eye area (Kirkland, Peterson, Baker, Miller, & Pulos, 2013), and at recognition of the identity of eyes with which they have been familiarized (Liu et al., 2012). Taken together, the data suggest females attend and respond to faces and eyes differently than males, starting from the earliest months of life. These studies leave open the question of which aspects of the face females and males are processing and retaining in these early months of life. If female infants attend more to the eyes and prefer to look at faces, and scan faces in a similar way to adult females, it could be that already at this young age, females are becoming eye and face experts more than males, and processing and retaining information from the eye area, including eye expressions, as well as the internal facial features, more than males, when encountering a face. Some empirical evidence points in this direction.

Female infants not only respond differently to faces in a canonical, front-facing view, they are also better than males at identifying specific faces in such a view. Several studies using a single, front-facing position of the face have found female superiority in recognizing familiar (e.g. Barrera & Maurer, 1981a, 3-month-olds; Bartrip, Morton, & de Schonen, 2001, 1- to 5-month-olds) and familiarized (e.g. Fagan, 1972, 5- to -6-month-olds) faces. A different pattern emerged when faces in various poses and various expressions were used. Three-month-old males, but not females, showed a preference for a novel face following a delay after habituation to a face in different poses (full frontal, three-quarter view, profile) and expressions (neutral and smiling). At test the familiarized face was presented in a new combination of pose and expression - the smiling full-frontal view - alongside the novel face in the smiling full-frontal view (Pascalis, de Haan, Nelson, & de Schonen, 1998). One possible interpretation of these results is that the males encode and/or retain information about the 3D structure of the face and the location of the features without regard to a change in the specific features (an expression change). This is while the females are either 1) unable to process or retain the structural information, or 2) can process the information, but do not have a preference for a smiling novel face over a smiling familiar face which had never been seen smiling directly at the child. When the authors (Pascalis et al.) habituated infants to the face in full frontal pose, both males and females showed a preference for a novel face following a delay. Taken together, the results of the infant studies suggest that females process the face in the canonical, full frontal view better than males, while males either process the 3D structure of the face and the layout of the features better than females, or disregard featural information, such as facial expression, more than females.

Further indication that infant males may be processing facial information in terms of configuration (i.e. the spatial location of the features in the face) rather than the specific features, and also in particular processing featural eye information less than females, is given by studies designed to test differences in processing between the two hemispheres in infancy. At 4-10 months (de Schonen & Mathivet, 1990) a right hemisphere (left visual field) advantage was found for identification of the mother's face presented for short durations, and the effect was stronger for males than for females. It was also found (Deruelle & de Schonen, 1998) that, in these ages, infants process configural information (eye size) in briefly presented faces better with their right hemisphere than with their left hemisphere, and featural information (eye shape) better with their left hemisphere than with their right hemisphere. These results suggest that, at this age, males process information in briefly presented faces using configural information, and their right hemisphere, while females use both hemispheres and process additional types of information, such as specific features, and the eyes in particular (see Proverbio, Brignone, Matarazzo, Del Zotto, & Zani, 2006 for similar findings in adults, of a lack of asymmetry for face processing in females, vs. a right hemisphere dominance in males). Thus, if infant males tend to use the right hemisphere for processing faces, they should be less sensitive than females to a change in the shape of the eyes. This is especially interesting since a change in the expression of the eyes may also sometimes consist only of a change in shape – suggesting males may be disregarding socially important information contained in facial expressions if they do not process and respond to featural changes in the eyes.

In the studies mentioned in the previous paragraph, stimuli were presented briefly to one visual field, and in many of the studies there was a learning task involved, in which differential reward served to direct the attention of the infants to the single difference between stimuli. Thus it is not clear from these studies what infants attend to, process and retain when there is no differential reward directing their attention to the change, and the presentation is not brief and not limited to one visual field and thus one hemisphere. My framework would suggest that, even when given more time to process the stimulus, and allowed to process with both hemispheres, males attend to and retain the structural information and the configural layout of the features, while females process the specific features as well. Indeed, when habituated to a face with only the identity of the eyes changed at test, 4-month-olds (7 girls, 15 boys) showed only a non-significant tendency to recover looking, while 6-month-olds (14 girls, 8 boys) did so significantly (Schwarzer, Zauner, & Jovanovic, 2007). No analysis by sex was mentioned, and sex was unbalanced, as can be seen. The results in the two groups did pattern in the predicted direction – in the group with more girls, a change in eyes was significantly noticed. Since the two groups also differed by age, however, the influence of infant sex on their differential performance is unclear. Also, the two faces used in the Schwarzer et al. (2007) study differed in gender, which may have also had an effect on the results (see, e.g., Quinn et al., 2002). Thus it is unclear from the current data whether males and females differ in their ability to detect changes in features in a female face, and in particular changes to the eyes, when no differential reward is present, and when the presentation is not brief and not limited to one visual field (one hemisphere). It is also unclear from this data whether infants process and respond to featural changes in eye expression in a different manner than to featural changes in eye identity, and if so, at which ages, as well as whether there is a sex difference in detecting featural changes in eye expression. These questions about eye expression processing are important both in terms of understanding the development of visual processing, and because of the importance of eye expression processing for social development. The findings above are also limited to a change in the eye area, and it is unclear from these findings whether male and female infants differ in detection of a larger change – a change in all internal features – or whether the sex difference in face processing development is limited to detection of changes in the eye area. The next section, which describes developments in face processing between early and later infancy, also describes a study that did look at detection of a change in all internal features.

1.5 Developmental changes in face processing between 5 and 7-8 months

Between the ages of 5 and 7-8 months, significant changes occur in infants' face processing. Evidence for holistic processing, in the sense of gluing the features together in a gestalt (see Maurer et al., 2002), has been reported for infants aged 8 and 10 months (Schwarzer & Zauner, 2003), but not 4-month-olds, while 6-month-olds are at an intermediate stage in which they process the mouth holistically (i.e. within the configuration of the face), but not the eyes (Schwarzer et al., 2007). When holistic processing of the internal features with the external features is considered, at least when tested with infant faces, infants aged 5 months detect a change in external features (hair, chin, ears, shape of head), but fail to detect a change in internal features (eyes, nose, mouth) in a face. By 7 months, infants are able to make both discriminations (Rose, Jankowski, & Feldman, 2008) (this developmental change in the ability to detect a change to novel internal features when the external features are held constant differs from what happens when infants are habituated to two different faces – in this case, it was found that when habituated to two upright female faces, both 4-, 5.75- and 7-month-olds detect a switch between the internal features of the two faces, while 6.25-month-olds do not detect the switch [Cashon & Cohen, 2004]. The developmental shift around 6 months was later found to be related to sitting ability [Cashon et al., 2013]). Thus, if female infants develop more quickly than males in terms of face processing, and/or if they attend to internal features more than males, a difference between the sexes in terms of detecting a change in internal features may be found at 5 months, but disappear by 7 months. Rose et al. (2008) did not find sex differences, but several methodological issues may have obscured sex differences, such as the use of infant faces as stimuli, rather than adult female faces usually used in face processing studies with infants due to the infants' greater experience with such faces, the use of infants of different ethnicities as subjects, without balancing sex within ethnicities, and the use of a manipulation that included configural in addition to featural changes.

The change from feature-by-feature to holistic processing of the internal features themselves may also lead to a difference between the way a change in one feature is processed and the way a change in all 3 features (eyes, mouth, nose) is processed. In adults, changing all three features leads to a right hemisphere advantage in detecting the change, while changing only one of the features (e.g. the eyes) leads to a left hemisphere advantage (Hillger & Koenig, 1991). Thus, similar performance by males and females at 7 to 8 months in terms of discrimination of a change in all three features, if found, may be due to the use by either or both sexes of a holistic processing strategy, rather than the processing of the change in the specific features, when all three features are changed. The females may still outperform the males in the case of a single feature change, at least when that feature is the eyes. Discrimination of a change of a single feature (eyes, nose, mouth) would then be tested in future follow-up studies, outside the scope of this thesis. However, 7- to 8-month-old males may be found not to respond to a change in all three internal features, when the external features are unchanged. This would mean that even at 7 months, males are not attending to the internal features in a static face or processing and retaining the internal features at a level that enables them to discriminate faces based on the internal features alone.

The switch to holistic processing of the internal features between 5 and 7 months may also affect the way static facial expressions are processed, as these may also now be processed holistically rather than in terms of one or more individual features. In addition, large changes occur between early and later infancy in the ability of infants to categorize facial expressions and assign meaning to the expressions, as reviewed in Chapter 3. Because of these developments in face processing between the two ages, the studies in this thesis examined the development of the ability to detect changes in eye expression and in facial features in these two ages.

1.6 Thesis rationale

The studies in this thesis aimed to elucidate aspects of visual processing that differ between males and females, at two ages in which infants differ in terms of motoric ability, as well as in terms of visual processing – 5 months (early period) and 7-8 months (later period). The studies and their specific predictions were informed by my integration of the literature reviewed above on the differential rate of development of the ventral visual stream together with the studies that have been done on face processing and mirror image processing in infancy. The over-arching hypothesis for all studies was that there are sex differences in visual processing in early infancy that stem from a differential rate of development of the ventral stream, with female development faster than that of males. In particular, I hypothesized that as part of this differential development, 5-month-old females would outperform males in processing internal features in the face, and that males would outperform females in discriminating between a familiarized object and its mirror image. Any advantages seen at one point in development could predispose the female infant to become even more interested in, and, due to the influence of visual input on visual processing development, more adept at, processing faces, and could have the opposite effect on males, leading to further divergence in development.

Since visual input in infancy is known to influence visual processing development, and face processing in particular, all studies equated infants on certain factors related to visual input known to be relevant to face processing development, such as the mother's ethnic appearance. In addition, all studies took an exploratory look at two factors which may have an effect on face processing by either or both sexes, due to their effect on the visual input the infant receives (see section 1.2) - the size of the social environment of the infant, in terms of the number of people with whom the infant is familiar, and the infant's level of locomotion. My hypothesis with regards to these two factors was always that a larger social environment and a lower level of locomotion would result in better face processing abilities.

Although there is some research to support my hypotheses with respect to the differential development of 5-month-olds males and females, many unanswered questions remain. Specifically, most of the studies to date were not designed to test the hypothesis that faster development of the ventral stream underlies some of the sex differences in visual processing in infancy. Hence, the stimuli selected, the designs used, and the ages tested by others were not selected to optimally test this hypothesis and left several holes. In certain cases, sex differences may have been obscured or even reversed due to the involvement of factors which allowed processing through the dorsal stream, lack of regard for important factors related to visual input, as described in the previous paragraph, etc.

Chapters 2 and 3 of this thesis aimed to determine whether there are sex differences in detection of featural changes in the eye area, and specifically in eye expression, in the early infancy period (Chapter 2), when the face stimulus is presented centrally (i.e. to both hemispheres) and not briefly, and whether similar sex differences are found in the later period (Chapter 3), after major changes have occurred in the infants' ability to process facial expressions as well as in holistic processing of facial information. I hypothesized that at the younger age, females would outperform males in detecting a change in eye expression, under conditions in which the attention of the infants is not directed in any way to the presence of any change, and in particular to a change in eye expression. Since previous research with full facial expressions at this age range indicated 5-month-old infants show a novelty preference both when habituated to a smiling expression and tested with a neutral expression, and when habituated to a neutral expression and tested with a smiling expression (Bornstein, Arterberry, Mash, & Manian, 2011), I hypothesized that 5-month-old females would show a novelty preference when habituated to a face with a neutral face and a smiling eye expression and tested with the same neutral face with a neutral eye expression. For the older group, it was not clear how the facial expression of smiling eyes in a neutral face would be perceived in infants who process the internal features of the face holistically, and it was also not clear whether the infants, who are now more advanced in facial expression processing, would show a preference for smiling eyes over neutral eyes, leading to a familiarity preference rather than a novelty preference. Therefore no specific hypothesis was presented as to the direction of difference between the older males and the females, or to the direction of preference in either sex.

To my knowledge, infants have never been tested on detection of a change in eye expression in a static face. Results of performance on a task looking at detection of a featural change in eye expression, in addition to advancing knowledge of sex differences in the development of ventral visual processing, will also advance knowledge of the development of facial expression processing, and of sex differences in processing of eye expression and of facial expression. As the processing of facial expressions is important for social interaction, results of an eye expression discrimination task also advance the knowledge of social development in infancy.

Chapter 4 aimed to determine whether there are sex differences in detection of a featural change in the internal facial features (eyes, nose and mouth), rather than only in the eye area, in the two age groups. I hypothesized that at 5 months, females would outperform males in the detection of a change in features, again under conditions in which the attention of the infants is not directed in any way to the presence of any change. For the older group no clear hypothesis was put forward, since infants at this age have been found to detect a change in all three features. Because of the focus in this thesis on face processing tasks that may efficiently be performed by the left hemisphere (changing the shape of the features – either one or all features), finding results consistent with the hypothesis of a more developed ventral stream with these tasks, would also be consistent with the hypothesis of a more developed ventral stream in the left hemisphere alone. Future studies would then be needed to determine whether there are any sex differences with respect to the development of the ventral stream in the right hemisphere.

Chapter 5 aimed to determine whether there are sex differences in the abilities of 5-month-old infants to discriminate between an object and its mirror image, when these are presented without motion and without a need for mental rotation in performing the task. Besides advancing knowledge about sex differences in the development of ventral visual stream processing, the results of such a task would help elucidate whether sex differences found in mental rotation in infancy are indeed related to mental rotation, or whether they can be explained by a sex difference in mirror image discrimination. In addition, Chapter 5 aimed to determine whether there is a relation between the ability to discriminate between an object and its mirror image and the ability to detect a change in eye expression. Exploring such a relation would further advance knowledge about the development of the ventral visual stream. With respect to the first aim, of determining whether there is a sex difference in 5-month-olds in discriminating between an object and its mirror image, I hypothesized that males would outperform females in mirror image discrimination. Additional test trials looked at the ability of the infants to discriminate between the object and an altered version of the object with the structure changed, to ensure that if females did not discriminate between the object and its mirror image, it was not simply due to incomplete processing of the structure of the object. Following the tests with the objects, a test of eye expression discrimination, using a different procedure than the one used in Chapter 2, was presented to the infants. This served as a replication for the results in Chapter 2, as well as to test for a within-subjects relation between mirror image discrimination and eye expression discrimination. I hypothesized that there would be a negative correlation between mirror image discrimination and eye expression discrimination, as infants more advanced in ventral visual stream processing were expected to show relatively low levels of performance in discrimination between an object and its mirror image but high levels of performance in discrimination of eye expression, while infants less advanced in ventral visual stream processing were expected to show a relatively high level of discrimination between an object and its mirror image and a relatively low level of discrimination of eye expression.

Chapter 6 discusses the findings of the experimental chapters, their contributions to the field of developmental cognitive neuroscience and to additional fields, their strengths and limitations, and future directions.

In summary, this thesis was designed to address the hypothesis that sex differences in visual processing can be explained, at least in part, on the basis of the rate of development of the ventral visual processing stream. To address this hypothesis and to track developmental changes, infants were tested on selective tasks – mirror image confusion and processing of facial features - that engage higher levels of the ventral visual processing stream.

There are 4 specific main aims:

Aim 1. Are there sex and age differences in detection of changes in eye expression?

I hypothesized that females would outperform males in showing a novelty preference at 5 months. (tested in Chapter 2, replication with a different paradigm in Chapter 5) . To examine how any observed differences progress across development, infants aged 7 to 8 months were also tested (Chapter 3). Here there was no a priori hypothesis.

Aim 2. Are there sex and age differences in detection of featural changes in the internal facial features (eyes, mouth, nose)?

I hypothesized that females would outperform males in showing a novelty preference at 5 months. To examine how any observed differences progress across development, infants aged 7 to 8 months were also tested. Again, there was no a priori hypothesis for this age group. (Both age groups were tested in Chapter 4).

Aim 3. Are there sex differences in mirror image discrimination at 5 months?

I hypothesized that males would outperform females. (Tested in Chapter 5).

Aim 4. Is there a relation between mirror image discrimination and eye expression discrimination at 5 months?

I hypothesized that mirror image discrimination would be negatively correlated with eye expression discrimination. (Tested in Chapter 5).

2 Sex Differences in 5-Month-Old Infants in Eye Expression Discrimination and Face Identity Discrimination

2.1 Introduction

What an infant learns and processes in the first months of life, as the brain is developing, forms a foundation for later learning. In some cases, for example infants with untreated cataracts (Lewis & Maurer, 2005), sensitive periods have been identified in which the lack of patterned visual input has long-term consequences for brain development and visual function. Yet even infants with no deficit in their sensory organs may differ in what they attend to, learn and process in these early months. One particular domain in which infants may differ at the end of this period is their visual processing, especially of faces, an often encountered stimulus in the infant's proximal environment in these months (Sugden et al., 2014). Infants emerging from this early period with different face processing skills may follow different visual and social developmental trajectories later on. The goal of this chapter is to examine one factor that may influence the development of face processing in this early period and beyond – the sex of the infant. In addition, this chapter, like the other experimental chapters in this thesis, takes an exploratory look at the relation between the development of face processing and two other factors – the infant's social environment, i.e. the people with whom the infant is familiar, and the infant's motor activity - and the possible interaction between the three factors. Two aspects of face processing will be examined – discrimination of eye expression, and discrimination of face identity.

2.1.1 Sex differences in attention to eyes and faces and in face processing

Sex differences in attention to eyes and faces and in face processing have been found in multiple studies, at various ages, though not in all studies. In terms of attention to eyes, females show a greater tendency to maintain eye-contact in live interactions, starting from early infancy (e.g. newborns, Hittelman & Dickes, 1979; 3-month-olds, Leeb & Rejskind, 2004), as well as at later ages – from 12 months up to adulthood (e.g. Lutchmaya, Baron-Cohen, & Raggett, 2002; Podrouzek & Furrow, 1988; Ashear & Snortum, 1971; Levine & Sutton-Smith, 1973). As for attention to faces relative to other stimuli in the environment, there are several studies which have found sex differences here as well. In one study (Connellan et al., 2000) neonates were sequentially presented with a naturally moving live, silent smiling female face and a constantly moving 3D mobile of this face scrambled. In this study a significant association was found between sex and stimulus preference such that, while more neonate males than would be expected by chance looked for a longer proportion of the time at the mobile than at the face, fewer female newborns preferred the mobile than would be expected by chance. Similarly, at the age of 6 months, when sequentially shown slides of faces and slides of stimuli such as checkerboards and bullseyes, in one study (Lewis et al., 1966) it was found females direct longer first looks as well as longer total looks to the face stimuli over the other types of stimuli, while the first looks and total looks of males to the various stimuli did not differ in duration. When objects and faces were presented simultaneously, Gluckman and Johnson (2013) found 6-month-old females look at faces for longer durations than males. These studies suggest that females attend to eyes and faces differently than males, looking at faces for longer durations than males relative to other stimuli in the environment, and looking longer than males at the eyes within a face, starting from the earliest months of life.

This female tendency for longer eye contact and attention to faces in the environment compared to males may increase females' experience with eyes and faces, and may lead to greater expertise in face processing, as well as better detection of changes to the eye area, whether they be changes in identity of the eyes or in eye expression. While the origins of the sex differences in attention to eyes and faces are not known, if they indeed manifest in different eye expression processing and face processing abilities already at this early period, this could have cascading effects on the development of facial expression processing in the two sexes.

There is evidence for greater discrimination performance of eye identity and eye expression in females compared to males throughout the lifespan, though not in the infancy period. For instance, when eyes are presented in isolation, female children (ages 8-9 years and 13-14 years) and adults are better than their male counterparts at detecting eye identity, in this case recognizing with which eyes they had been familiarized (Liu et al., 2012). Adult females are also better than adult males at identifying emotions from the isolated eye area (Kirkland et al., 2013). When facial expression processing in general, rather than eye expression alone, is considered, meta-analyses have revealed a female advantage starting from infancy and continuing to adulthood (McClure, 2000; Hall, 1978; Thompson & Voyer, 2014). Some adult studies suggest the female advantage in recognizing facial expressions is related to greater attention to the eyes (Hall et al., 2010; Vassallo, Cooper, & Douglas, 2009). It is plausible that the female advantage in recognizing facial expressions in infancy and childhood may also be related to a difference in attention to eyes. There is indeed some indication that greater attention to the eyes enhances the ability to detect a change of expression in infants, at least for some expression contrasts – Amso, Fitzgerald, Davidow, Gilhooly, and Tottenham (2010) found that for infants between 6 and 11 months of age, greater proportion of gaze directed at the eye area correlated positively with a novelty preference for a happy emotion following habituation to fear.

Taken together, the research reviewed above indicates that starting from early infancy, females make more eye contact than males, which may increase the female expertise in processing information from the eye area. Furthermore, females also discriminate facial expressions better than males starting from early infancy, and the ability to discriminate facial expressions has been linked to attention to the eyes both in infancy and in adulthood, suggesting females may indeed be processing information from the eye area, including eye expression, more than males, already in early infancy. However, although adult and children females have been found to perform better than males on tasks requiring processing of the eye area, it is currently unknown whether female infants show a similar advantage compared to male infants with respect to the detection of changes to the eye area, and to changes of eye expression in particular. My first hypothesis is thus that at 5 months, female infants will outperform male infants in the ability to detect changes in eye expression.

In terms of discriminating face identity, in infants, studies using a single, front-facing pose of the face have often found female superiority in recognizing familiar faces (e.g. Field, Cohen, Garcia, & Greenberg, 1984; Barrera & Maurer, 1981a; Bartrip et al., 2001), and familiarized faces (e.g. Fagan, 1972). This suggests that female infants process the canonical, full frontal view of the face better than males. A different pattern emerged when faces in various poses and various expressions were used. Three-month-old males, but not females, showed a preference for a novel face following a delay after habituation to a face in different poses (full frontal, three-quarter view, profile) and expressions (neutral and smiling). At test the familiarized face was presented in a new combination of pose and expression - the smiling full-frontal view - alongside the novel face in the smiling full-frontal view (Pascalis et al., 1998). The results suggest the males encode and/or retain information about the layout of features and/or the 3D structure of the face without regard to a change in the specific features (an expression change).

This is while the females are either 1) unable to process or retain the configural and structural information, or 2) can process the information but do not have a preference for a smiling novel face over a smiling familiar face which had never been seen smiling directly at the child. Taken together, these results suggest that infant females process the face in the canonical, full frontal view better than males, while male infants either process configural and structural 3D information in a face more efficiently than females, or disregard featural information, such as facial expression, more than females.

The female advantage in face recognition has also been found in children (e.g. Rehnman & Herlitz, 2006) and adults (Rehnman & Herlitz, 2007; McBain et al., 2009; Sommer et al., 2013), though in some studies this advantage interacts with the gender of the viewed face, with females found to be better than males at recognizing female faces, but not better than males at recognizing male faces (see, e.g. Herlitz & Lovén, 2013). Interestingly, a recent study (Bolhuis, Kolling, & Knopf, 2016) suggests that infants aged 6 to 9 months who show a higher interest in the eyes during the study, are better at discriminating a novel face from a face to which they had been habituated, at least when the faces differ mainly in featural (i.e. local) information. Thus, the tendency to focus on the eyes may contribute to the female advantage in discriminating between faces. Taken together, the studies suggest that even after receiving enough time to process a face (i.e. following habituation as opposed to familiarization), female infants may be better at discriminating a novel face from the habituated face, especially when changes to the external features and to the relations between the external features and the internal features are minimal. Thus, my second hypothesis is that 5-month-old female infants will be better than males at discriminating a novel face from the habituated face.

2.1.2 Effects of experience on face processing

In addition to the infant's individual level of inclination to interact with people and to look at their faces and eyes, another factor that influences an infant's experience with faces is the faces he or she encounters during the day. The specific faces with which an infant has experience have been shown to be important for face processing. This is evident, for instance, in infants' face preference and face discrimination abilities for faces of a certain race and a certain sex. For race, 3-month-old infants, but not neonates, prefer to look at own-race faces over faces from other races (e.g. Bar-Haim et al., 2006; Kelly et al., 2005; Kelly et al., 2007) and 3-month-olds have also been found to be able to discriminate between two faces of their own race better than between two faces of another race (Sangrigoli & de Schonen, 2004, see also Hayden, Bhatt, Joseph, & Tanaka, 2007), though in other studies this phenomenon, deemed the other-race effect, or own race bias, and found through adulthood (see, e.g., Meissner & Brigham, 2001), was found to emerge at slightly older ages (e.g. between 3 and 6 months, Kelly at al., 2009). As for sex, Quinn et al. (2002) found that 3- to 4-month-old infants with female primary caregivers preferred female faces, while infants with male primary caregivers preferred male faces (though the sample size of infants reared by males was small). In addition, they found that infants with female primary caregivers also showed recognition memory for individual females but not males. However, Quinn at al. (2002) did not look at the infant's experience with individuals other than his or her primary caretaker, which may also have affected face expertise. Indeed, research using parental questionnaires at 2, 5, 8, and 11 months (Rennels & Simmons, 2008) and research using a head mounted camera worn by the infants aged 1 and 3 months (Sugden et al., 2014) has revealed that for infants with female primary caregivers, the majority of infants' facial experience was with their primary caregiver, females, and other individuals of the same race and age-range as their primary caregiver. The increased experience with female individuals in addition to their caregiver may have contributed to their face expertise with respect to females. However, those studies (Rennels & Simmons, 2008; Sugden et al., 2014) that looked at infants' experience with faces did not attempt to relate the individual infants' experience with their face processing abilities.

When it comes to race, there is research that points in the direction of the broader social environment, rather than the primary caretaker alone, influencing face processing development, as, for example, 3-month-old Ethiopian infants who had been living in a predominantly Caucasian environment did not demonstrate a preference between the two race groups, unlike Caucasian infants in a Caucasian environment or African infants in an African environment, who preferred faces of their own ethnicity (Bar-Haim et al., 2006). Also, 3 year old children with siblings have been found to process faces differently than 3 year old children without siblings (Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009; Macchi Cassia, Pisacane, & Gava, 2012), which again suggests additional people in the infant's social environment, other than the primary caretaker, may affect the development of face processing. Hypothesis 3 of my study is that the individual infant's experience with different faces, and perhaps with Caucasian females in particular, will influence his or her face discrimination abilities. Since males and females attend to faces differently, it is unclear whether the effects of faces in their environment will influence their face processing abilities to the same extent. Therefore the effect of environment will be analyzed for each sex separately. If such effects are found, they could explain some of the null results in research on sex differences in face processing in infancy, as sample sizes are typically rather small in infant studies, and individual differences in social exposure in a particular sample could obscure the sex difference.

In addition to influencing face recognition, some research indicates that an infant's individual experience with faces has an effect on his or her facial expression processing abilities as well. For instance, at 3 months, infants are better able to discriminate smiling from frowning expressions when the mother is posing these emotions than when they are posed by a stranger (Barrera & Maurer, 1981b). Infants aged 3.5 months prefer smiling expressions over neutral when posed by a female, but neutral expressions over smiling expressions when posed by a male, which is again suggested to be influenced by their differential experience with female and male faces (Bayet et al., 2015). Finally, Gredebäck, Eriksson, Schmitow, Laeng, and Stenberg (2012) found that, for 14-month-old infants, the distribution of parental leave (in this study – whether the infant's primary caretaker is the mother for the last month, or caretaking is split between the mother and the father over the last month) affects the infant's processing of facial expressions, in terms of scanning patterns and pupil dilation responses. Therefore the effect of the infant's social environment on the discrimination of eye expressions will be examined as well.

2.1.3 Effects of motor activity on face processing

Very little work to date has explored the influence of motor activity on face processing, but the few studies that have been done point to some potential relations. Libertus and Needham (2014) found that motor activity at 3 months is related to face preference, in the sense that less motor activity is correlated with higher preference for a face over a toy. They did not find similar findings in a group of 5-, 9-, and 11-month-olds, and suggest this may be due to reduced variability in infants' preference scores and motor activity scores at the older ages. However, since my study looks at face processing, and not face preference, a preference for faces at 3 months may result in better face processing capabilities at 5 months. Therefore, in this study, I also looked at motor activity. My hypothesis was that low motor activity will be related to better face processing, for either or both sexes. The factor of motor activity is particularly interesting because some studies suggest there is a sex difference in motor activity, starting from infancy (e.g. Eaton & Enns, 1986; Campbell & Eaton, 1999), and thus differences in motor activity may underlie some of the sex differences found in the development of face processing. In the current study I looked at level of locomotion, which is one of the factors of motor activity. Level of locomotion has also recently been found to affect the infant's visual field and the proportion of time in which faces are in the infant's visual field (Kretch et al., 2014), which adds to the likelihood of this factor affecting experience with faces and face processing.

2.1.4 The current study

In the present study, infant discrimination of eye expressions was tested using an infant-controlled habituation procedure, which allows each infant to process the stimulus at his or her own pace. Infants were habituated to a static picture of a female face, and then presented with a test phase which consisted of a sequential presentation of 3 different stimuli: the habituation stimulus, and two other stimuli – one in which the eyes were replaced with the eyes of the same person but in a different eye expression, and one of a different face in a similar pose to the habituation stimulus. Sequential rather than simultaneous side-by-side presentation of the test stimuli was chosen to make the task slightly more reflective of the infant's true capacity to detect a change in eye expression, as when a person changes expression outside the lab and out of the infant's view (i.e. not dynamically) the infant cannot compare the previous expression to the current expression simultaneously, and attention to the eye area is required to even notice that any change has occurred. Side-by-side presentation of the stimuli would enable the infant to compare the images and notice they differ in the eye area, even if his or her attention is not endogenously drawn to the eye area of the face during the test trial, and then only need to recall which of the eye expressions had been used in habituation. Thus the task tests a combination of eye expression discrimination and attention to the eye area. Also, in general, evidencing a novelty preference in successive test trials has been found to be more difficult for infants than in side-by-side test trials (Caron, Caron, Minichiello, Weiss, & Friedman, 1977), and my intent was to make the task relatively difficult, to increase the chance to find individual and group differences.

The focus of the current study was the discrimination of eye expression, and thus the novel face always appeared in the last two test trials. This enabled verification that if a group of infants did not evidence discrimination between the novel and familiar eye expression, it was not because they had fatigued or lost attention to a level in which even a larger change, to a novel face with a novel eye expression, was no longer detectable. Since the novel face always appeared at the end, and the presence of the novel eye expression may have influenced the subsequent looking to the novel face identity in infants who had detected the change in eye expression, any findings with respect to face identity discrimination must be followed up by future studies outside the scope of this thesis that do not include intervening eye expression change stimuli.

A face with a neutral expression but for a smiling eye expression was chosen to be the habituation stimulus (with the same face with a completely neutral expression serving as the novel eye expression stimulus), rather than the reverse order in which the face with the completely neutral expression is the habituation stimulus, for several reasons. First, when full facial expressions were used, 5-month-olds were found to show both a novelty preference for a neutral expression following habituation to a happy expression, and a novelty preference for a happy expression following habituation to a neutral expression (Bornstein et al., 2011), thus the order of stimuli was not predicted to influence the eye expression discrimination results in the current study, and a novelty preference was predicted in the infants who detect the change in eye expression. Second, in previous infant studies of static facial expression discrimination in which a happy expression was one of the expressions to be discriminated, when the order of stimuli was found to affect performance, it was in the direction that familiarization/habituation to the happy expression and testing with a different expression resulted in a novelty preference, while familiarization/habituation to the other expression did not result in a novelty preference when the happy expression served as the test stimulus (e.g. happy-fear: Nelson, Morse, & Leavitt, 1979, happy-surprise: Ludemann & Nelson, 1988), thus habituation to the partial happy expression may be more likely to elicit a novelty preference than habituation to the neutral expression. Finally, when face identity discrimination is considered, a happy facial expression in familiarization, even a partial happy expression, has been found to improve face identity discrimination compared to a neutral facial expression in familiarization (e.g. Brenna, Proietti, Montirosso, & Turati, 2013). For these reasons the order of expressions chosen was considered at least as likely to produce discrimination (both of eye expression and face identity) in those infants who process the eye expression as the reverse order.

The male and female infants were chosen to be the same ethnicity (Caucasian), same birth-order (all first born), and in a small age range, as these are all variables suggested to affect face processing abilities. Parent questionnaires were used to obtain additional variables that may be related to performance but on which the infants from the two groups were not matched. It was hypothesized that, at 5 months, females would outperform males in eye expression discrimination, as well as in face identity discrimination. It was also predicted that a larger social environment would lead to greater discrimination of eye expression and of face identity, as will a lower level of locomotion.

2.2 Methods

2.2.1 Participants

Twenty infants were included in the final sample (*M* age = 153 days, *SD* = 6 days, range 137 to 162 days): 10 females (*M* age = 153 days, *SD* = 7 days, range 137 to 162 days), 10 males (*M* age = 153 days, *SD* = 6 days, range 143 to 161 days). All were first-born, healthy and full term (at least 38 weeks gestation), living in a two parent home. All infants were Caucasian, except for one female whose father was half Caucasian half Latin-American. Infants were recruited by contact with new parents at the local maternity hospital in Vancouver and by community flyers and referrals. The criterion for being included in the analysis was completing the first 5 of the 6 test trials, with a minimum looking time of 1 second in each. One infant (female) in the final sample completed only the first 5 test trials due to equipment malfunction, the rest completed all 6 test trials. Additional infants were tested but excluded from for the analyses for the following reasons: 9 due to crying (3 females, 6 males), 1 due to parental interruption during the test period (female), 1 due to not completing the first 5 test trials (male), 2 due to equipment failure (1 male, 1 female).

2.2.2 Stimuli

The stimuli used for habituation and test were color images of two Caucasian female adult faces. Three pictures of the two female faces were used to create the stimuli in the study - two pictures of one of the females (female A) – one with a neutral expression (picture A1), and one with a smiling expression (picture A2), and one picture of the other female (female B), with a neutral expression (picture B). The pictures were taken from the Radboud Faces Database (RaFD), an initiative of the Behavioural Science Institute of the Radboud University Nijmegen (Langner et al., 2010). Adobe Photoshop was used to crop part of the hair of the two females (to increase attention to the internal facial features instead of the hair), to remove noticeable blemishes and scars, to insert a gray background, and to insert the eye expression from the picture of female A with the smiling face (picture A2) to the picture of the same female with a neutral face (picture A1), replacing the neutral eye expression with the smiling eye expression. The faces were 26 cm high and 19 cm wide (hair included), which were 22.6 x 16.6 degrees of visual angle when viewed from a distance of approximately 65 cm. The images (including the neck and shoulders) were set against a gray rectangular background of 39 cm high x 37 cm wide. The entire frame was, in turn, set against the black background of the TV, thus effectively flanked by 2 black stripes, one on either side.

Stimuli images:

Figure 2.1. Habituation stimulus/familiar face (F) test stimulus – picture of female A with neutral overall expression, but with the eyes taken from a picture of the same female smiling. Hair cropped, background gray (with black vertical stripes at the edges of the image when presented on the screen)

Test stimuli (in addition to habituation stimulus, which is the familiar stimulus) –

Figure 2.2. Familiar face novel eye expression (NE) – picture of female A with neutral overall expression, and eyes also with neutral expression.

Figure 2.3. Novel face (NF) - Female B, neutral expression.

Figures 2.4, 2.5: Test trial order, ordered from left to right (each stimulus presented alone, mid-screen, for 2 consecutive trials) –

Figure 2.4. Test trial order 1: F NE NF

or

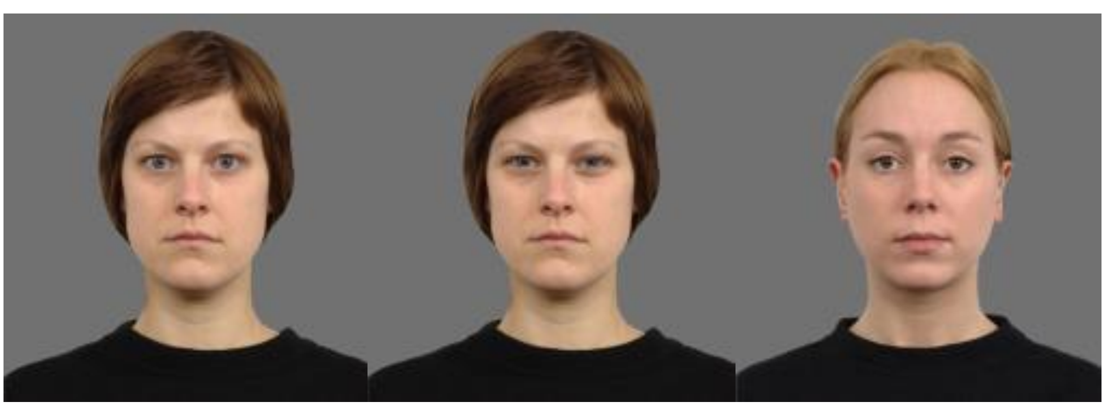

Figure 2.5. Test trial order 2: NE F NF

2.2.3 Procedure

Each infant was tested in a dimly lit, sound attenuated room. The infant was seated on a parent's lap approximately 65 cm in front of a 32-inch plasma television screen on which the stimuli were presented. To prevent parents from influencing their babies' looking times, the parents' vision was blocked by opaque sunglasses, and they were instructed not to speak or point. A low-light video camera was used to record the infant's face and present it on a computer to an experimenter in another room. The experimenter controlled the study with a computer running the Habit 2002 program (Cohen, Atkinson, & Chaput, 2002). The experimenter pressed a button when the infant began fixating the stimulus on the screen, and released the button when the infant stopped fixating the stimulus. The duration of each trial was under the infant's control. Each trial was preceded by 2 seconds of black screen followed by an attention getter which was a static image of a red cross on a gray background, set against the black background of the TV screen. Once the infant fixated the red cross, the stimulus of the trial was presented. The trial continued until the infant looked away for 1.5 seconds (or 120 seconds had elapsed, but no infant reached the 120 second time limit on any trial).

The first trial was a pretest trial, in which the stimulus presented was a photograph of a field of tulips. After the pretest trial, the habituation phase began, during which the habituation stimulus (a face with a neutral expression in which the eyes with a neutral expression were replaced with smiling eyes) was presented in each trial until the infant's looking time decreased to criterion level. To reach criterion, the infant's looking time during 3 consecutive trials had to total 50% or less of the peak looking time – the total looking time in the 3 consecutive trials with the longest total looking time up to that point. A sliding window was used, thus the minimum possible number of trials to habituation was 4. The maximum number of trials to habituation was set to 16.

The subsequent test phase consisted of 6 trials - 2 trials with the original image (F – familiar face – face with a neutral expression in which the neutral eyes were replaced with smiling eyes), 2 trials with the same image except for a change in the eye area (NE – novel eye expression – the same neutral face as in F, but with the original eyes with a neutral expression), and 2 trials with a novel face (NF - in a similar pose to the habituation stimulus, and a neutral expression). There were two test orders, counterbalanced between infants – F F NE NE NF NF, and NE NE F F NF NF. That is, the first 4 test trials were 2 trials with the familiar face followed by 2 trials with the familiar face novel eye expression, or 2 trials with the familiar face novel eye expression followed by 2 trials with the familiar face. These 4 trials were always followed by 2 test trials with the novel face. The test phase was followed by a post-test trial, which was identical to the pretest trial.

Following the test phase, the infant and parent returned to the waiting room. An ethnicity questionnaire was administered to the parent by the experimenter, in which the experimenter interviewed the parent about the people with whom the infant is familiar, and their ethnicities. Additional questionnaires, including a child characteristics questionnaire, were administered to the parent, and then the infant received a diploma and a small gift for participating.

The videos recorded during the study were later coded offline frame by frame by a trained coder, at a rate of 29.97 frames per second, for infant looks to and away from the stimulus, and measures of looking time were obtained from this offline coding.

For the purpose of the current study, two social environment variables were extracted from the ethnicity questionnaire – number of people the infant meets (besides his or her parents) at least once a week, for at least an hour (familiar people), and number of adult Caucasian females the infant meets (besides his or her mother) at least once a week, for at least an hour (familiar adult Caucasian females). Regarding motor activity, in the child characteristics questionnaire, parents were asked "What is your child's current most advanced mode of getting around (no motion, rolling over – to either or both sides, scooting on bum, creeping, crawling, walking, etc.)?" Two motor activity scores were extracted – locomotion (0 – no, 1 – yes), and level of locomotion (0 – no motion, 1 – rolling over, 2 – advancing forward in some way).

2.3 Results

2.3.1 Habituation phase

Male and female infants did not differ in number of trials to habituation, $t(18)=.992$, $p=.334>.1$ (M males=6, SD=3.62; M females=7.7, SD=4.03), total looking time during habituation, $t(18)=.057$, $p=.955>.1$ (M males=121.69, SD=77.3; M females=123.61, SD=73.28), length of first look to the first presentation of the habituation stimulus, $t(18)=0.388$, $p=0.703$ (M

males=17.15, *SD*=13.08, *M* females=14.9, *SD*=12.77), or in longest first look in the habituation phase, $t(18)=.221$, $p=.828$ (*M* males=19.2, *SD*=12.56, *M* females=18.01, *SD*=11.54).

To examine the pattern of looking over trials during the habituation phase, a 2 (sex) x 2 (trial type: peak, criterion) mixed-model ANOVA was conducted, with trial type (average looking time on the 3 peak trials, average looking time on the three criterion trials) as the repeated measure. The only significant effect was a main effect of trial type, $F(1,18)=47.65$, $p<0.00001$, $\eta^2_p=0.73$ (*M* looking time on peak trials for males=26.14, *SD*=15.23, *M* looking time on criterion trials for males=10.55, *SD*=6.5. *M* looking time on peak trials for females=23.99, *SD*=13.4, *M* looking time on criterion trials for females=8.56, *SD*=3.4), consistent with the presence of habituation.

2.3.2 Test phase

Lewis et al. (1966) found that first looks during a trial were a better index of discrimination than total looking time during a trial. Therefore the measure of the duration of the first look to the first trial of each type was the measure analyzed. Infants' mean first look duration to the first trial of each test trial type (familiar, novel eye expression, novel face) are shown in Figure 2.6.

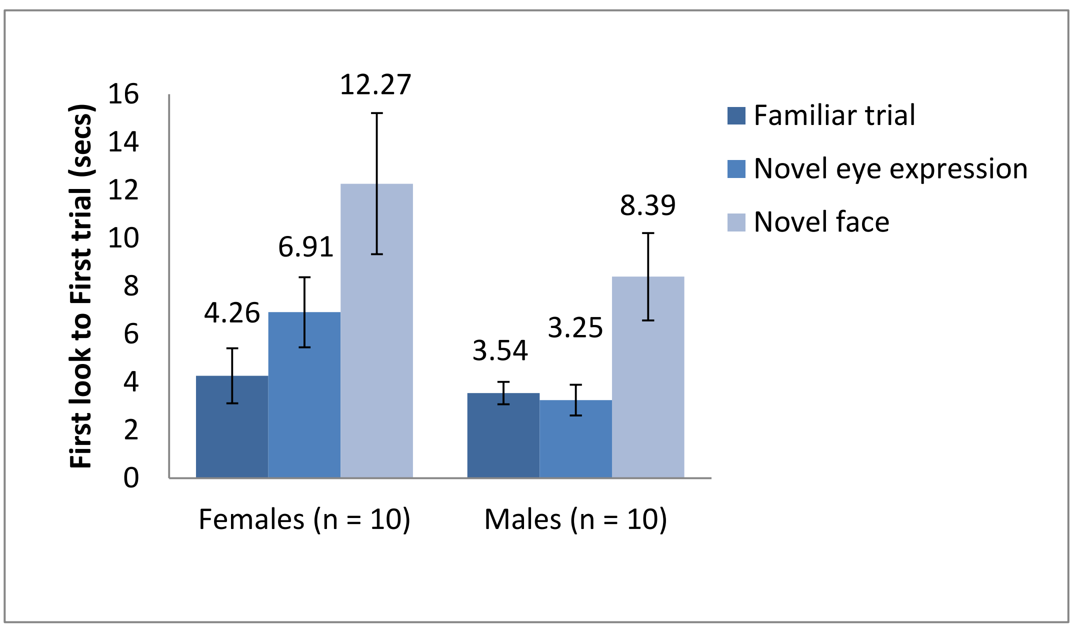

Figure 2.6. Mean first look duration to the first test trial of each type, by sex, at 5 months

Eye expression discrimination

To test the first hypothesis of the study, whether female infants discriminate between different eye expressions of the same face better than male infants, an eye expression discrimination score was calculated for each individual by dividing the duration of the infant's first look to the first novel eye expression test trial by the sum of the duration of the first look to the first novel eye expression test trial and the duration of the first look to the first familiar test trial. Figure 2.7 shows the mean discrimination scores for the two sex groups. Since discrimination is usually inferred by a novelty preference, i.e. in this case a longer duration of looking to the novel eye expression over the familiar eye expression, and since a novelty preference was found in a similar study using full face neutral and smiling expressions with 5-month-olds (Bornstein et al., 2011), a one-tailed t-test comparing the mean eye expression discrimination score to chance (0.5) was conducted on each of the two groups. For females, the mean eye expression discrimination score was M=0.62, SD=.18, $t(9)$=2.086, p=0.034 (one-tailed), effect size (Cohen's d) = .66, thus their mean discrimination score was significantly greater than 50%. For males, the mean eye expression discrimination score was M=0.46, SD=.13, $t(9)$=.945, p=.82 (one-tailed), *ns*. Since the hypothesis was that females would outperform males in eye expression discrimination, a one-tailed independent samples t-test comparing the discrimination score mean of the males to the discrimination score mean of the females was also conducted, and its results were: $t(18)$=2.246, p=0.019 (one-tailed), effect size (Cohen's d) =1, that is the female discrimination score mean is significantly greater than the male discrimination score mean, as predicted.

A one-tailed Fisher's Exact Test comparing the proportion of the females who had an eye expression discrimination score higher than the chance score of 0.5 (80%) to the proportion of the males who had a discrimination score higher than 0.5 (30%) yielded results that were significant at the $p<0.05$ level: p=0.035.

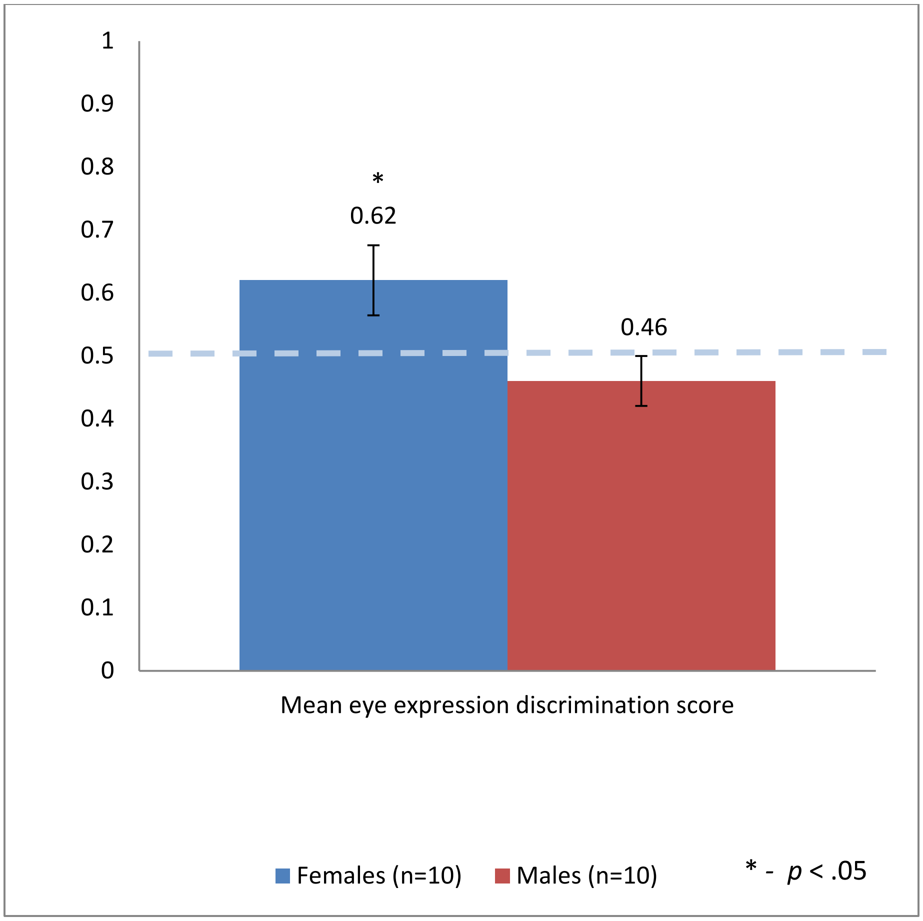

Figure 2.7. Mean eye expression discrimination scores, by sex, at 5 months

Face identity discrimination

A similar discrimination score was calculated for the novel face trials, by dividing the duration of the infant's first look to the first novel face test trial by the sum of the duration of the first look to the first novel face test trial and the duration of the first look to the first familiar test trial. Figure 2.8 shows the mean face identity discrimination score for the two sex groups. In this case, both sexes had a mean discrimination score significantly greater than 0.5. For females, M=.72, SD=.14, $t(9)$=5.131, p (one-tailed)=0.0003, effect size (Cohen's d) =1.62. For males, M=.63, SD=.17, $t(9)$=2.411, p (one-tailed)=0.02, effect size (Cohen's d) =0.76. A one-tailed t-test comparing the female mean face identity discrimination score to the male mean face identity discrimination score (assuming the females would discriminate better) was not significant – $t(18)$=1.297, p (one-tailed)=0.106, effect size=0.58, and Levene's test for equality of variances also only approached significance (p=0.082), with the male variance in performance larger than the variance of the females. A one-tailed Fisher's Exact Test comparing the proportion of the females who had a face identity discrimination score higher than 0.5 (90%) to the proportion of the males who had a discrimination score higher than 0.5 (80%) produced non-significant results: p=0.5.

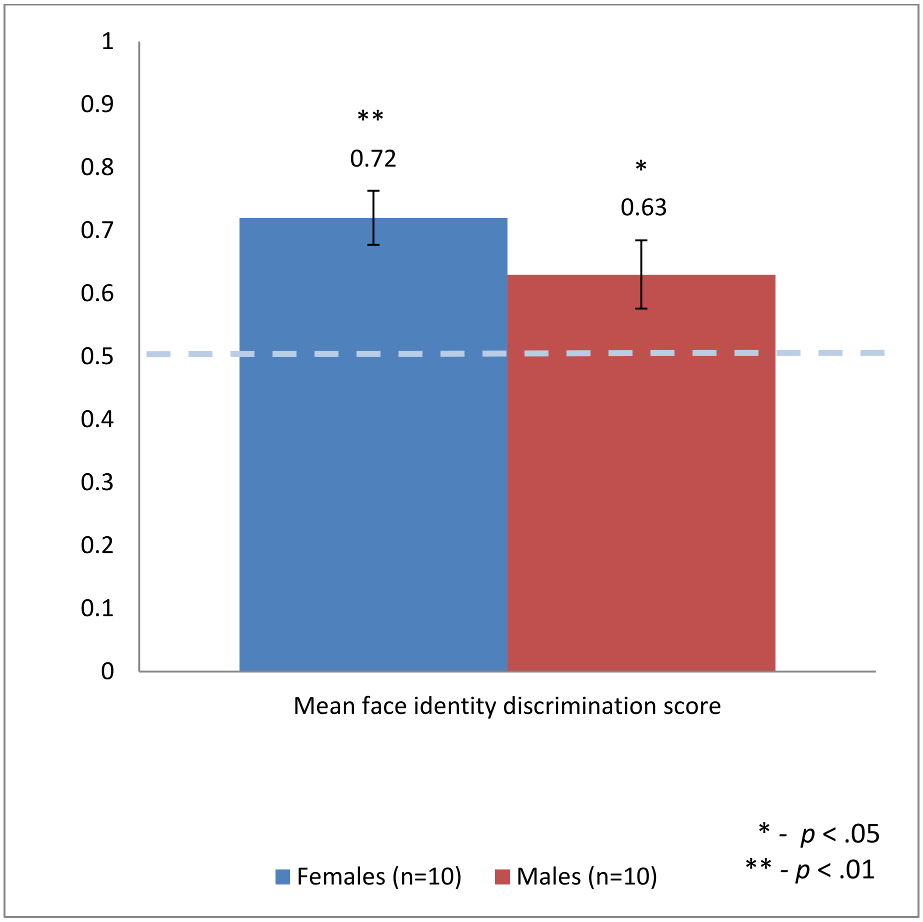

Figure 2.8. Mean face identity discrimination scores, by sex, at 5 months

Relation between social environment and locomotion variables and discrimination for the two sexes

For my exploratory analysis, the relation between the social environment and locomotion variables and discrimination was analyzed for each sex separately, as it is unknown whether these factors influence the discrimination performance of infants of the two sexes in the same way. To look at the effects of social environment and locomotion variables on face identity discrimination and eye expression discrimination, I calculated the correlation of each of the 4 variables (familiar people, familiar adult Caucasian females, locomotion, locomotion level) with each of the two discrimination scores (face identity discrimination and eye expression discrimination). Spearman rank order correlation rather than Pearson correlation was used in the correlations involving the locomotion variables since they are ordinal variables. For the males, the correlations involving the social environment variables were run with the lg10-transformed social environment variables (x transformed to lg10(x+1)), due to skewness. As the locomotion level of the males was constant (all males were at level 1, rolling over), the two variables pertaining to locomotion could not be correlated with the discrimination measures for the male group.

The results for the males were: For face identity discrimination, the correlation with the lg10-transformed number of familiar people was r=.735, p (two-tailed) = 0.015. Figure 2.9 shows the relation between the non-transformed number of familiar people and the face identity discrimination scores – as can be seen from the graph, infants with a small number of familiar people (3 or less) had scores that were under 0.55, while infants with a larger number of familiar people had scores that were over 0.65. Similarly, the correlation with lg10-transformed number of familiar adult Caucasian females was r=0.723, p (two-tailed) = 0.018. For eye expression discrimination, neither correlation was significant. The correlation with the lg10-transformed number of familiar people was r=0.085, p (two-tailed) = 0.815, and the correlation with the lg10-transformed number of familiar adult Caucasian females was r=0.346, p (two-tailed) = 0.327.

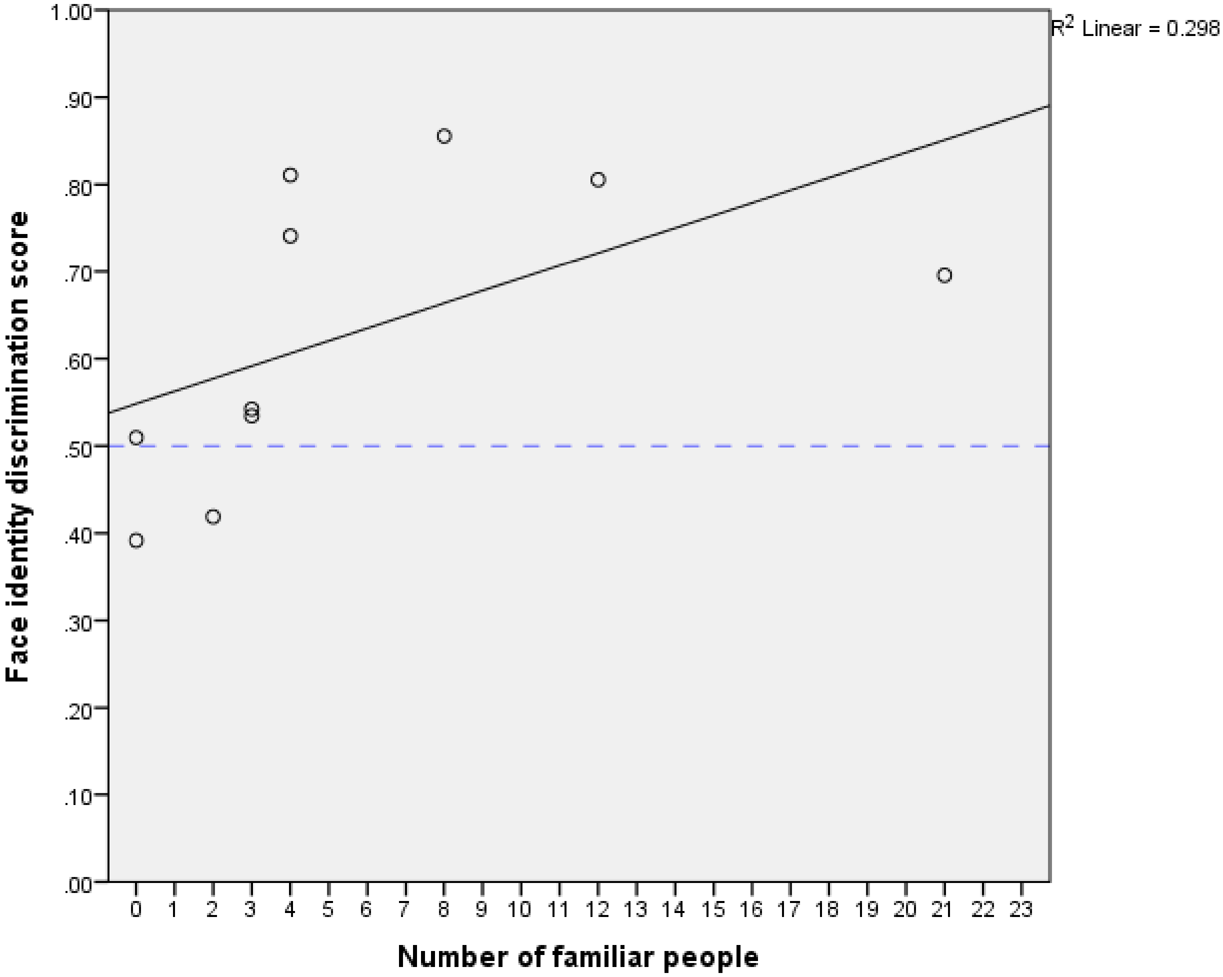

Figure 2.9. Relation between number of familiar people and face identity discrimination – 5-month-old males

These results suggest that for males, the social environment variables (i.e. the number of people the infant knows, or the number of Caucasian adult females the infant knows) are related to face identity discrimination. From the current sample no conclusions can be made about the relation between locomotion development and face identity discrimination or eye expression discrimination for males, since there was no variance in level of locomotion in this sample.

The results for females were: For face identity discrimination, Spearman's rank order correlation with locomotion level was r_s= -0.562, p(two-tailed)=0.091, that is, there was a trend towards a significant negative correlation between face identity discrimination and level of locomotion. The trend was in the predicted direction, with less mobile infants showing a higher level of discrimination – see Figure 2.10.

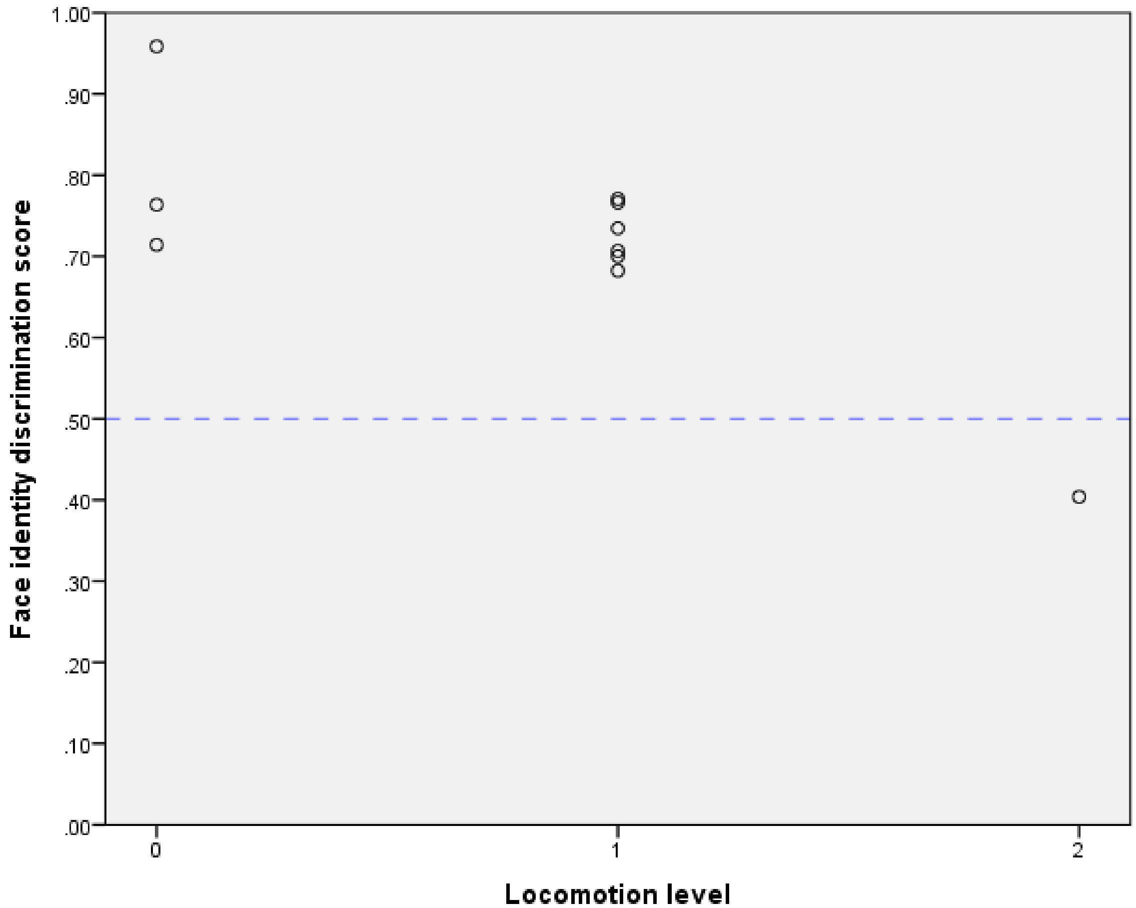

Figure 2.10. Relation between locomotion level (0 – no motion, 1 – rolling over, 2 – advancing forward in some way) and face identity discrimination – 5-month-old females

None of the other variables were significantly correlated with face identity discrimination (see Figure 2.11 in the Appendix for the relation between face identity discrimination and number of familiar people, with level of locomotion marked). Note that face identity discrimination had low variance for the females, except for two extreme scorers on face identity discrimination, and the correlation with locomotion level is driven by these two extreme scorers – an infant with a high novelty preference with no motion, and an infant who preferred the familiar face who was creeping. When these two infants are removed, the effect weakens, and the correlation is no longer significant. Therefore these results should be treated with caution.

For eye expression discrimination, the correlation with familiar Caucasian adult females was significant. The results were, however, in the unexpected direction – the correlation was negative, so that the more adult Caucasian females the infant is familiar with, the less likely she is to prefer to look at a change in eye expression from happy to neutral, $r = -0.706$, p (two-tailed) $= 0.022$ – see Figure 2.12. Spearman's rank order correlation with locomotion was $r_s = -0.798$, p (two-tailed) $= 0.006$, i.e. there was a significant negative correlation (see Figure 2.13 in the Appendix), and Spearman's rank order correlation with locomotion level was $r_s = -0.583$, p (two-tailed) $= 0.077$, i.e. there was a trend toward a significant negative correlation. Again the correlation was negative, so that the infants who had no motion showed better eye expression discrimination than the ones who rolled or creeped. The correlation between eye expression discrimination and familiar people only approached significance at the $p<0.05$ level: $r = -0.618$, p (two-tailed) $=0.057$.

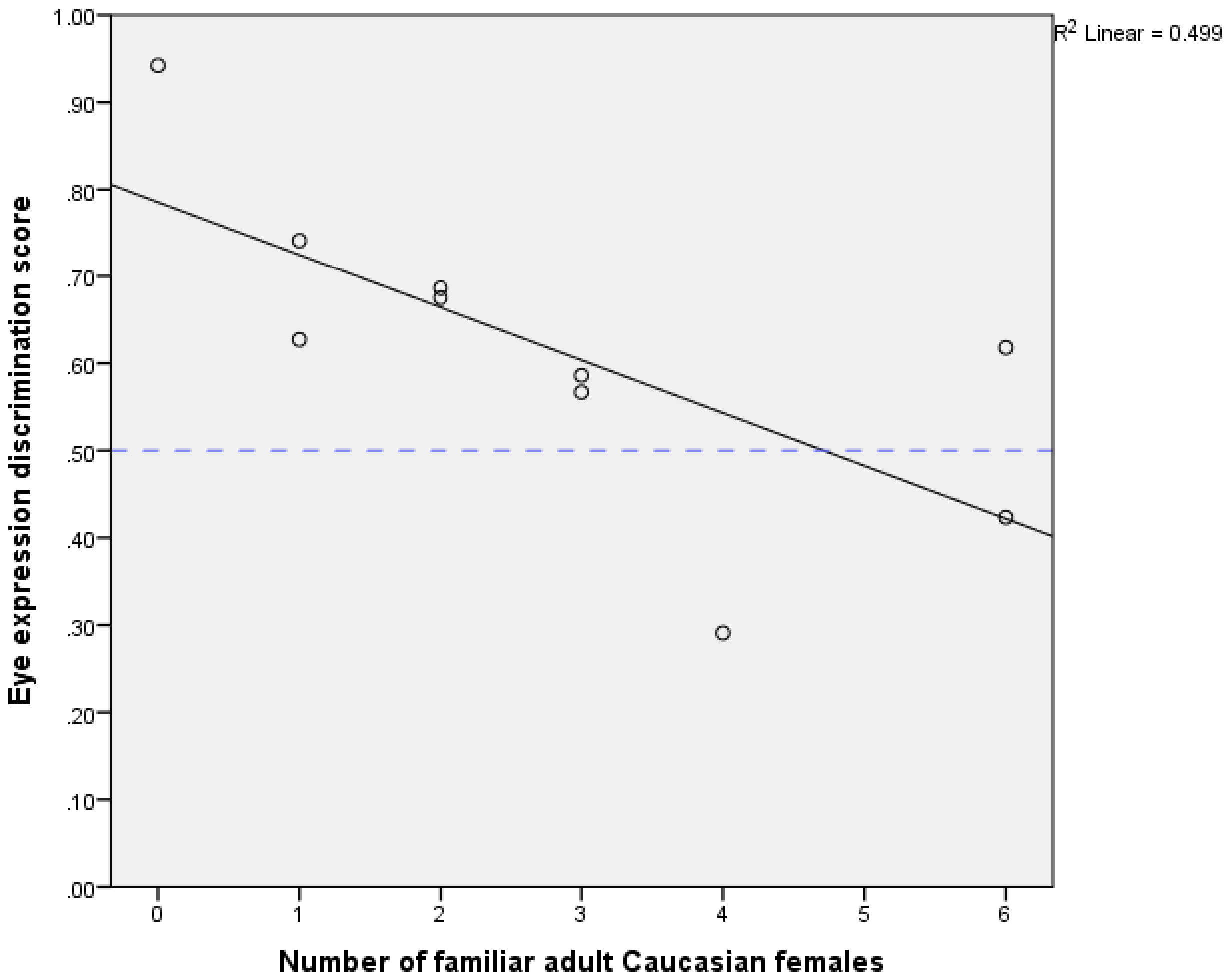

Figure 2.12. Relation between number of familiar adult Caucasian females and eye expression discrimination – 5-month-old females

These results suggest that for females, locomotion status is predictive of face identity discrimination and eye expression discrimination performance (with a lower level of locomotion associated with better discrimination), while the number of familiar adult Caucasian females was found to correlate negatively with eye expression discrimination in terms of preferring a novel neutral eye expression over a smiling one, but social environment did not relate to face identity discrimination. However, the results for the face identity discrimination for females need to be treated with caution for two reasons. First, there was little variability in face identity discrimination performance for the females, perhaps due to ceiling effects, except for 2 extreme scorers. Second, since females discriminated the eye expression, it is difficult to interpret their face identity discrimination results, because their performance in detecting the novel face is not independent of their performance in detecting the novel eye expression, as, for instance, the presence of the novel expression indicated to the females that some change in the face may occur and may have increased their vigilance for a possible change. For the males, since no evidence of detecting a change in eye expression was found, the relation between the number of people familiar to the infant and his performance on detection of a novel face is less likely to be spurious.

2.4 Discussion

The current study has produced several interesting findings, which will now be discussed in turn. To my knowledge, this is the first study to test infants on discrimination of eye expressions in static faces. The use of infant controlled habituation in this study rather than a learning task such as that used in Deruelle and de Schonen (1998) for studying discrimination of featural changes in the eyes, makes the results more likely to reflect infants' sensitivities outside the experimental setting. As hypothesized, when using infant-controlled habituation, 5-month-old females were found to outperform males in eye expression discrimination, when only a featural change was involved. The current findings add to the knowledge about sex differences in face processing, and suggest that females are already becoming "eye experts" at this early age compared to males. Since eye expression is a meaningful social signal, this finding also has implications for studies of sex differences in social development, and suggests that, in addition to face processing developmental trajectories, female and male social developmental trajectories are already starting to diverge at 5 months. These results also support the hypothesis of a sex difference in visual processing through the ventral stream at 5 months, with females being more advanced in ventral visual processing than males. There was also a trend towards females outperforming males in face identity discrimination, as well as a trend towards a difference in variance (with male performance more varied than females). These findings, as well, strengthen the evidence for females' precocious face processing abilities compared to males. However, the face discrimination results, especially for the females, need to be treated with caution, as the novel eye expression discrimination may have influenced the face identity discrimination score.

The design of this particular study does not enable separating the effects of attention from effects of processing and from effects of memory. The test trials were presented just as the habituation trials were – as an infant controlled presentation of a face stimulus in the center of the screen, with no indication that any change had occurred. The habituation procedure may also have had a negative effect on the infants' attention and vigilance. The fact that infants in both sex groups preferred the novel face identity above chance suggests both groups of infants were alert enough to detect a large change in the stimulus. However, only the females evidenced detection of the change in the eyes. To perform this discrimination, females had to attend to and encode the eye area in the original stimulus, retain the information over the inter-trial stimulus interval, attend to the eye area in the first looks in the novel eye expression test trials, and detect that a change in the eye area had occurred compared to their internal representation of the original stimulus. The males, who did not discriminate, may have failed at any or all of these stages.

If males did encode the original eye area in the habituation phase and retained it during the inter-trial interval, but only failed to attend to the eyes in the test trials, it is possible that with a different procedure, such as one in which in the test trial the original stimulus and the novel stimulus are presented side by side, the males will be able to demonstrate discrimination abilities – this is explicitly tested in Chapter 5. Presenting the stimuli side by side following familiarization or habituation to a single stimulus alerts the infants to the fact that some change has occurred, facilitates detection of the difference between the stimuli (in this case – an eye expression change) by placing the images side by side and enabling the infants to compare the images directly, and novelty preference in this case requires only the ability to recognize which of the stimuli had been presented before. If in follow up studies males are found to succeed with side-by-side presentation of stimuli differing in eye expression, this will point to the main difference between the sexes being not in the encoding process, as both sexes will have fully encoded the eye expression enough to perform the discrimination, but in other aspects of the task, such as the locus of their attention – with the female tendency to continuously attend to the eye area contributing to their ability to detect changes to the area.

Another question unanswered by the current study is whether the sex difference in eye expression discrimination performance remains stable throughout infancy, especially since many changes in face processing and in the processing of facial expressions occur during the first year of life, and particularly between 5 months and 7 to 8 months. This question is addressed in Chapter 3. Equally interesting and important would be to elucidate whether the sex difference in discrimination of featural changes at this age is limited to discrimination of eye expression/a change to the eye area alone, or if there is a sex difference in discrimination of facial expressions/changes to internal features in general. I explore internal feature discrimination more directly in Chapter 4.

Research on the origins of differences in face processing between the sexes may also have implications regarding Autism. If the same pattern of sex differences in development is exaggerated in autism, as would be predicted by a developmental interpretation of the ‘extreme male hypothesis’ (for hypothesis, see Baron-Cohen, 2002), this may be an important part of the pathway that leads to the full-blown disorder. Thus, in addition to improving our knowledge of infant social and visual processing development in general, research on early sex differences in visual processing and face processing may lead, further on down the line, to a better understanding of Autism and to better treatments. Indeed, recent findings suggest that infant males later diagnosed with Autism show a decrease in looking to the eyes between 2 and 6 months (Jones & Klin, 2013), which is not found in typically developing infant males. Looking at variables related to the differences in eye and face processing between the sexes and within the male group may help understand which factors may be contributing to this decline, and in general to the visual and social developmental trajectories in Autism.

In this study, in addition to the sex of the infant, an exploratory look was taken at two additional variables – motor activity and social environment. The first variable, motor activity, represented by locomotion in this study, was found to be correlated, in females, with both eye expression discrimination and face identity discrimination, though some of the correlations only approached significance. The correlations found were in the predicted direction – infants with lower levels of locomotion showed greater discrimination than infants with higher levels of locomotion. These results suggest level of locomotion is indeed an important factor to consider in studies of the development of face processing. In males it was not possible to test the relation between motor activity and face identity or eye expression discrimination with the sample in the study, since all males were in the same locomotion stage. Since no locomotion (i.e. lower motor activity) was associated with better discrimination, this suggests the male tendency for greater motor activity (Eaton & Enns, 1986; Campbell & Eaton, 1999), which was reflected in the samples in this study as well, may contribute to the differences in face processing abilities between the sexes, starting in early infancy. A more informative score of motor activity, including the time of onset of locomotion as well as other factors of motor activity, may shed more light on the relation between motor activity and face processing development in infancy. It is interesting to note that with respect to sitting ability, a U-shaped curve has been found with respect to holistic face processing (Cashon et al., 2013), with non-sitters and established sitters performing better than infants in the stages of learning to sit. Sitting is similar to non-locomotion in the opportunity it provides for stable observation of a face, and thus the combination of sitting and stage of locomotion may be an even better predictor of face processing abilities. Unfortunately, the sitting status of infants was not examined in the current study. It would also be interesting to look at how the various stages of locomotion interact with eye and face processing. The motor activity factor, as well as motor development, may also be related to the development of face processing in autism. It should be noted that the motor factor has been found to affect performance of 7-month-old infants in categorization studies that did not include faces, as well – with lower motor activity associated with better performance (Vonderlin, Pahnke, & Pauen, 2008). Thus it may be that motor activity does not affect face processing alone, but also general performance in familiarization/habituation tasks – whether due to influence of motor activity on visual processing/cognitive development and/or attention in general, or due to the influence of motor activity on the performance of tasks of this kind in the experimental setting.

The second variable examined in this study was the social environment of the infant, measured here in terms of the number of people and the number of adult Caucasian females the infant knows. This factor affected males in the predicted direction – more familiar people correlated with better face discrimination, suggesting for infant males the size of the close social environment is an important factor in the development of face processing, with a larger social environment leading to more developed face processing abilities. Thus, future studies of individual and sex differences in the development of face processing should take the factor of the size of the social environment into account. For females this relation was not found, and although there may have been an interaction in females of face discrimination with eye expression discrimination, as mentioned, it is possible that the different interaction style of females, for example in terms of their tendency for longer eye contact and loss of the preference for the mother's face over a stranger's face at an earlier age than males (Bartrip et al., 2001), makes them less dependent on familiar people for the development of face processing, and more able to advance in face processing skills even from encounters with unfamiliar people. In this study the measure of social environment, number of familiar people, did not bring into account either the amount of contact with these familiar people (beyond specifying a required minimum) or the interaction between the familiar people and the infant. The types of interaction may be important as interaction style of the mother has been shown to affect face processing development, e.g. in terms of face expression discrimination (e.g. Kuchuk, Vibbert, & Bornstein, 1986). Future studies should take these additional factors into account, to examine how much of the infant's face processing abilities are dependent on the people around him or her, perhaps using methods like the head mounted camera method (Sugden et al., 2014) to examine these variables.

The influence of familiar people in the infant's environment, and perhaps for males in particular, on face processing has implications for autism, as well. In this study, all except one (a paid babysitter) of the familiar people were the parents' family and friends (including neighbors). The number of people an infant sees at least once a week for at least an hour is thus determined by his parents' social interactions - the number of friends they have, the frequency with which they get together with family and friends, etc. This means that, first of all, the infants' parents' social tendencies may have been confounded with the number of people the infant meets. These social tendencies of the parents are, in turn, influenced by both genetic and environmental factors, and so it cannot be said with certainty that my results are a consequence of the social environment of the infant and not influenced by the genetic makeup the infant inherits from his parents. Conversely, relative social isolation, or the behavior of the caretaker in interactions with familiar and unfamiliar people, as well as the caretaker's tendency to enter into such interactions, could influence an infant's face processing and attention to faces, and may be one of the reasons for the high heritability of autism spectrum disorder (ASD). Future studies may examine this question by relating an infant's social environment, his parents sociability (e.g. their scores on the AQ test (Woodbury-Smith, Robinson, & Baron-Cohen, 2005)), and the infant's attention to faces and face processing skills. Matching parents on sociability will enable to test the effect of the actual exposure to familiar people and the interaction with them, as can interventions to increase the infant's repertoire of familiar people.

The finding that for females the number of familiar adult Caucasian females correlated negatively with eye expression discrimination is surprising. One possibility is that increased exposure to familiar adult Caucasian females leads to an expectation for interaction or for speech, neither of which occurred in the study, and thus the females lost interest. Another possibility is that the additional females gave the infants an opportunity to be exposed to a variety of facial expressions, and thus lowered the salience of the absence of smiling eyes. At any rate, this result, like the others in the study, needs to be replicated in another sample before any solid conclusions can be drawn.

There are several limitations to this study. The sample sizes were small, in part due to the effort made to control variables that may obscure the sex differences, such as maternal ethnic appearance, birth order, and age of the infants. Although controlling these variables enables detecting a sex difference more precisely, and with a smaller sample, many additional variables not controlled in this study may have come into play and affected the results. For instance, Bornstein et al. (2011) found that discrimination of facial expressions at 5 months is related to the level of maternal depression. Data about maternal depression was not collected in this study, and it is possible that the distribution of maternal depressive symptoms was unequal in the two groups. This again points to the need for replication of this study. In addition, only one set of stimuli was used in this study as habituation and test stimuli. Use of a larger set of stimuli would ensure the results are generalizable and not specific to the current set of stimuli. Finally, testing populations other than Caucasian populations, with appropriate stimuli, would enable to determine whether this early sex difference in processing of eye expressions is a universal phenomenon in humans, or whether it is specific to certain populations.

2.5 Conclusion

Females and males differ in their abilities to process facial expressions of emotion, including eye expressions. This study revealed similar differences between females and males at 5 months, in terms of eye expression discrimination, suggesting the visual and social developmental trajectories of males and females are already starting to diverge at this young age. Motor activity and social environment also influence the face processing capabilities of infants, and may obscure sex differences, and should be taken into consideration when conducting studies about sex differences, as should the race, birth order and age of the children. Since male and female infants differ in levels of motor activity, this may also influence the differences in face discrimination between the sexes, at least at certain ages. Looking at factors that contribute to individual and sex differences may aid in understanding the development of social development disorders, such as ASD. Understanding what underlies the different developmental trajectories of these disorders may ultimately lead to better treatments, as well as better understanding of human development in general.

3 Developmental Changes in Infancy in Eye Expression Discrimination and Face Identity Discrimination

3.1 Introduction

The period between 5 and 7 to 8 months is a period full of developmental changes. In particular, many changes occur in face processing, including in the processing of facial expression. In Chapter 2 I found sex differences between infants at 5 months of age, in the ability to discriminate between eye expressions, as well as exploratory evidence for relations between the ability to perform eye expression and face identity discriminations and between social environment and motor variables. One of the unanswered questions from the study in Chapter 2 was whether the sex differences in discrimination ability remain stable throughout the infancy period, or whether the sex differences change with age. This question is addressed by the current study. In the study in Chapter 2, infants were habituated to a female with smiling eyes, but a neutral expression in the rest of the face. At test the infants were presented with test trials with the habituation stimulus (familiar test trials), test trials with the same image but with the original neutral expression of the eyes (novel eye expression test trials), and test trials with a different female (novel face test trials). Only females displayed longer first looks to the first presentation of the novel eye expression test trial compared to their first looks to the first presentation of the familiar test trial, with a trend towards more variable face identity discrimination performance in the male group compared to the female group. In the current study I used the same paradigm to test infants aged 7-8 months on the ability to detect a change of eye expression and a change of face identity. As in the previous study, the goal was to look at sex differences in these abilities, and also continue to explore the effects of social environment and motor development factors on the development of face processing. In addition, I combined the data from the current study with the data from the previous study to look for developmental differences in these abilities, both within each sex group and combining the groups.

3.1.1 The development of facial expression processing in infancy

Major developmental changes in facial expression processing have been shown to occur in the first year of life, and particularly between the ages of 5 months and 7-8 months.

Preferences for certain emotional expressions over others emerge and change with development, and there is also evidence that points to an enhanced ability to extract emotional information from the face and from the eye area in particular with age. Depending on the paradigm used, developmental changes in facial expression processing may result in various changes in performance with age, e.g. either an increase or a decrease in novelty preference for a specific novel expression over another, familiarized, expression may arise with development. For instance, order effects are sometimes found at certain ages, such as a decline in novelty preference when familiarizing or habituating the infants to a currently preferred expression and looking for an increase in looking to the novel, non-preferred expression over the preferred expression. In this case, the infant's tendency to prefer novelty is in competition with the tendency to prefer one expression over the other (see, e.g. Quinn et al., 2011). Sex differences in the development of facial expression processing have also been found in some studies, though many studies do not report the exact numbers of infants of each sex, do not report analysis by sex, or use group sizes that are too small to detect differences.

Using habituation, familiarization, and visual-preference methods, studies have shown that infants can discriminate between certain expressions posed by the same model at least by the age of 3 months (e.g. Barrera & Maurer, 1981b – smile and frown; Young-Browne, Rosenfeld, & Horowitz, 1977 – happiness vs. surprise, but not happiness vs. sadness), including neutral and happy. Three-month-old infants prefer happy faces over neutral faces presented side by side when a female model poses the expressions (Kuchuk et al., 1986, Bayet et al., 2015), but neutral faces over happy faces when a male model poses the expression (Bayet et al., 2015). Order effects are already found at this young age, as infants habituated to a sad expression dishabituate (i.e. look longer to the novel expression relative to the short looking time to the familiar expression at the end of the habituation process) to a surprised expression, but infants habituated to a surprised expression do not dishabituate to a sad expression (Young-Browne et al., 1977). Studies using a single model posing the expressions also indicate that 7-month-olds (Nelson & Dolgin, 1985; Kotsoni, de Haan, & Johnson, 2001; Peltola, Leppänen, Mäki, & Hietanen, 2009), but not 5-month-olds (Bornstein & Arterberry, 2003; Peltola et al., 2009), prefer to look at a fearful expression over a happy expression. Seven-month-olds also show order effects in the discrimination of fear vs. happiness expressions, such that 7-month-old infants familiarized with a model with a happy expression, look longer to the fear expression at test, but do not look longer to the happiness expression after familiarization with a fearful expression (e.g. Nelson et al., 1979).

Discrimination studies such as those described above, which use a single model simply displaying two expressions, do not point to the information the infants are using to perform the discrimination. The infants may be using featural information (such as the shape of the mouth, the presence of teeth, the shape of the eyes, etc.), they may be using configural information in the sense of second-order relations (distance between the features, see Maurer et al., 2002), such as the change in distance between the mouth and the nose or between the eyes and eye-brows that accompanies a change in facial expression, and they may be processing the expression holistically, as a gestalt (Maurer et al., 2002). Using a single model, Bornstein et al. (2011) showed that 5-month-old infants whose mothers were not clinically depressed could discriminate between a neutral and a smiling expression. The smiling expression used was a large toothy smile, which may or may not have been the basis for the discrimination (see below). In Chapter 2, I found that female, but not male, 5-month-olds, could also discriminate between neutral and smiling eye expressions in a neutral face, i.e. when the only change was a change in the eye expression. This suggests that female infants are able to make the discrimination between the two expressions on the basis of a featural change in the eyes, though it does not indicate whether the female infants interpreted the two expressions as smiling and neutral, whether any emotional content was attached to the expressions, or even whether the infants interpreted the two images as the same person posing different expressions or as different identities.

One method researchers have used to explore what information infants may use to discriminate between facial expressions is categorization studies. In these studies, several models posing the same expression are presented in the familiarization/habituation phase. Longer looking in the test phase to a novel model displaying a novel expression vs. the same novel model displaying the familiar expression is taken as indication that the infants were able to categorize the expression shown in the first phase, and recognized that the familiar expression was an instance of that category while the novel expression was not (but note that an a priori preference for exemplars from one category over exemplars from the other category may result in a novelty preference at test that is not related to the first phase, when the non-preferred expression is presented in the familiarization/habituation phase. This will result in an order effect, and when an order effect is found, it is not possible to tell whether the infant performed any categorization. See Quinn et al., 2011). Varying the information presented in the faces in the habituation phase enables testing what information the infants are able to use to categorize the expressions, though this does not mean that the infants came into the study with these preformed categories, but only that they were able to extract them in the learning phase. Caron, Caron, and Myers (1982) showed that, when happy faces have toothy smiles and narrow eyes, and surprised faces are non-toothy and wide-eyed, 7-month-old infants, but not 4-month-olds or 5.5-month-olds, are able to categorize happy and surprised faces. More specifically, when habituated to 4 female models posing one expression, 7-month-old infants looked longer to 2 novel models posing the novel expression over the same 2 novel models posing the familiar expression, while 5.5-month-olds looked longer only when habituated with happy faces and tested with surprised faces, and 4-month-olds did neither. In the Caron et al. (1982) study, females outperformed males at all ages, with 4-month-old females performing at the level of 5.5-old-males. Caron et al. reasoned that the females, who outperformed the males, responded to the "expressive aspects of the face", while the males attended mostly to the identities of the faces. Another possibility is that females, at least in some of the age groups, encoded some commonalities between the internal features of the faces in the habituation phase (either in the eyes or in the mouth or in both) and were able to discriminate between the novel expressions on the basis of those common features, either because they had a preformed category for these expressions that was based on these features, or due to categorization during the study, while the males were not able to categorize by these internal features until a later age. A developmental switch in the opposite direction, between categorization at 4 months (de Haan & Nelson, 1998) and an order effect at 7 months (e.g. Nelson, et al., 1979; Nelson & Dolgin, 1985; Ludemann & Nelson, 1988), has been found for fear vs. happiness, which is to be expected with the switch to a preference for looking at fearful faces over happy faces sometime between 5 and 7 months. Thus, in terms of the ability to discriminate between facial expressions, the direction is not always that of better performance with age. One suggestion for the order effect in discrimination and categorization performance in the 7-month-olds is that the infants are better able to encode and categorize a familiar expression and discriminate it from another expression (Ludemann & Nelson, 1988).

In contrast to Caron et al. (1982), Ludemann and Nelson (1988) found order effects with 7-month-olds in a study of categorization of happy and surprise, when the expressions in the habituation phase varied in intensity (i.e. some were toothy, some not, in some the eyes were more open, etc.) – infants recovered to surprise following familiarization to happy, but not vice versa. This supports the suggestion that the infants in the Caron et al. (1982) study were using the features of the expressions, and/or the combination of features, rather than more general categories of expressions of emotion (i.e. happiness and surprise), to categorize the expressions in the familiarization phase. Caron, Caron, and Myers (1985), in a follow-up study to Caron et al. (1982), showed that, in 4- to 7-month-olds, categorization of exemplars with non-toothy smiles resulted in recovery to models with a toothy smile, while categorization of exemplars posing toothy anger did not result in recovery. Caron et al. (1985) deduced infants were responding to non-relevant features of the expressions (i.e. toothiness) in their categorization. Only by 8 months, did infants not recover to the toothy smile following habituation to non-toothy smiles, suggesting the category of smiling they had formed during habituation included toothy smiles. The lack of recovery of 8-month-olds to a toothy smile is interesting, because it suggests by the age of 8 months, infants are able to categorize smiling faces not only based on the degree of openness of the mouth and the appearance of teeth. Though there are many ways that this can be achieved (e.g. the curved mouth, the combination of the curved mouth with the narrow eyes, etc.), one possibility is that around 7 to 8 months, there is a developmental shift to being able to use eye expression information for identifying some emotions, including the emotion of happiness, from static faces. If it is indeed the case that eye expression is used to detect emotion, then perhaps only changes signaling emotionally relevant eye movements draw attention, such as the switch from a neutral eye to a wide eye in a fear expression, or from a neutral eye to a smiling eye, but not vice versa. Alternatively, the reason for the preference of one direction over the other, e.g. in the case of the preference for fearful over happy expressions at 7 months, may be based on lower level visual differences drawing the infants' attention to the change – such as a large increase in the amount of sclera exposed in a fearful expression relative to the neutral or happy expression or the eye area becoming a more complex stimulus in the smiling expression relative to the neutral expression.

There is indeed some indication that at 7 months there is an increased attention to the eye area to discriminate emotion, in comparison to 5 months, as well as indication that 7-month-old infants, but not 5-month-olds, are able to extract the emotion from facial displays of emotion. In studies of bimodal audio-visual matching of emotions, two videos of the same individual reciting the same text with different emotions are presented side by side on the screen, and bimodal matching is indicated by an increased looking to the sound-specified emotion. While both 5-month-olds and 7-month-olds are able to match the emotion in face and voice in this method (Walker, 1982), only 7-month-olds, and not 5-month-olds, are able to match the emotion in face and voice (in this case angry vs. happy) when the mouth is obscured (Walker-Andrews, 1986), suggesting 5-month-olds were using the synchrony between the lip movement and the voice, and not the emotional content, to match the input from the two modalities. Seven-month-olds are also able to match the bimodal information of the emotions neutral and happy in the full face when the auditory information is played 5 seconds out of synchrony with the visual information (Walker, 1982). Five-month-olds were not tested for matching emotional tone of adults in face and voice without synchrony, and 7 months were not tested without synchrony when the mouth was obscured, but this is in line with additional information about 7-month-olds being able to detect a change of emotion from a talking face without the addition of sound, while 5-month-olds are only able to detect a change of emotion in voice (Flom & Bahrick, 2007). Taken together, these studies suggest a shift between 5 and 7 months to being able to use visual displays of the face, and even of the eye area alone, to extract emotional information, at least when dynamic displays of emotion are involved.

With respect to neutral vs. happy emotions, 7-month-old infants will follow the gaze of an adult posing a neutral expression more often than when the adult is posing a happy (or sad) expression, and will also look longer to the target (Flom & Pick, 2005), suggesting the infant's attention is differentially engaged by happy versus neutral expressions. The behavioral data presented above is supplemented by studies using ERP measures. Based on these studies, 7-month-olds are able to detect some form of emotion from static expressions, and for at least some facial expressions, from the eyes alone. Seven-month-olds are able to detect whether the emotion (happy or angry) in a static facial expression that precedes a word is congruent or incongruent with the emotion in the spoken word (Grossmann, Striano, & Friederici, 2006), suggesting that by 7 months, infants are able to recognize affect in the static face and in the voice, and integrate the information. Seven-month-olds exhibit heightened sensitivity to happy faces over angry faces, in terms of a larger Nc amplitude in their ERPs for happy than for angry facial expressions, and thus presumably greater allocation of attentional resources to the happy expression, as well as showing a visual preference for happy faces over angry faces when presented side by side (Grossmann, Striano, & Friederici, 2007). Specifically for eye information, 7-month-olds discriminate between fearful and non-fearful eyes, even when the information is presented very briefly (Jessen & Grossmann, 2014), while 5-month-olds do not (Jessen & Grossmann, 2016).

To sum up, research on the development of processing of facial expressions points to a developmental shift between 5 months and 7-8 months in terms of the ability of infants to attach emotional meaning to facial expressions. At 7 months, emotional expressions such as happiness seem to engage the infant's attention more than a neutral face, and there is evidence of an ability to process emotional information without information from the mouth (in the case of dynamic stimuli of happiness and static fear stimuli). However, since the matching of information from the eye area for happy expressions has only been demonstrated in dynamic stimuli at 7 months, while from Caron et al. (1985) the possibility arises that only at 8 months do infants, as a group, attend to eye information for the processing of static happy emotions, it may be that the 7 to 8 month range is a transitional period in terms of processing static happy emotions from the eye area, and that females are more advanced than males in this ability, at least in this age range.

3.1.2 Some relevant aspects of the development of internal feature processing between 5 months and 7 to 8 months

Previous research (Schwarzer & Zauner, 2003; Schwarzer et al., 2007) has found evidence of a shift from a featural or feature-focused style of processing of the internal features, at 4 and 6 months, to a more holistic style of processing, in which the internal features (eyes and mouth) are processed in conjunction with each other, at 8 and 10 months. This shift to a more holistic processing style could have at least two implications for the current study. First of all, the shift to holistic processing of the internal features may also translate to holistic processing of facial expression – and thus a face with a half smiling expression (smiling eyes but a neutral mouth) may be perceived (by either or both sexes) as strange or unfamiliar at 7 to 8 months, rather than as smiling.

The second possible implication is that the shift to a more holistic processing style and less of a focus on the eyes as an individual feature, may lead to a less complete processing of the eye area during habituation – with the infants processing the identity/configuration of the face, resulting in a reduction in their looking time to the point of reaching the habituation criterion, but without completing the processing of the expression/features. Scott and Nelson (2006), found that, at 8 months, infants familiarized for 20 seconds of accumulated looking time with a face, showed a familiarity preference for the familiarized face compared to the same face in which the features (eyes and mouth) were replaced with the features from a different face, and a novelty preference when the familiarized face was compared to the same face with altered second order relations (i.e. the distance between the eyes and the distance between the mouth and nose were changed). This suggests that at least at 8 months, configural information may be processed before the processing of featural information has completed. From the Scott and Nelson (2006) study, it cannot be said whether longer familiarization periods would lead to an eventual switch to a novelty preference for a change in features, and if so, how long the familiarization periods need to be for that switch to occur. A shift from a familiarity preference with short familiarization times to a null preference with longer familiarization times to a novelty preference with even longer familiarization time is a pattern commonly found in infant studies (e.g. Rose, Gottfried, Melloy-Carminar, & Bridger, 1982; Hunter, Ross, & Ames, 1982; Richards, 1997), thought to reflect the speed of information processing, with more complete processing leading to a novelty preference. Thus, the shift from featural to holistic processing of the internal features may lead to a familiarity preference for a change in features (in this case a featural eye expression change), even following habituation, if processing of the eye expression was not completed during habituation.

3.1.3 The current study

In the current study, 7- to 8-month-olds were tested with the same procedure as in Chapter 2. The infants were habituated to a static picture of a female face with a neutral facial expression except for the eye area which had a smiling expression. Following habituation, the infants were presented with a test phase which consisted of a sequential presentation of 3 different stimuli: the habituation stimulus, and two other stimuli – one was the same as the habituation stimulus, except for the eyes which were displaying a neutral expression like the rest of the face, and one was a different face in a similar pose, with a neutral expression. In Chapter 2, 5-month-old females showed a novelty preference for the face with the novel, neutral eye expression over the familiarized face with a smiling eye expression. Since a happy expression seems to be preferred to a neutral expression at 7 months, at least in terms of the ability to disengage attention from the stimulus, and also since the half smiling expression may be unfamiliar and difficult to process for the infants, if the infants process the information from the eyes in conjunction with the information from the mouth, the order in which the infants in my study are tested (from the preferred/unfamiliar to the non-preferred/familiar expression) may lead to a null preference or even a familiarity preference. A familiarity preference or null preference not related to the order of presentation may also arise due to the shift from featural processing to holistic processing of the internal features, as described in section 3.1.2. Alternatively, a null preference may also be a result of both expressions being perceived as neutral, due to the absence of a smiling mouth expression, or due to failure to detect the change in eye expression. Finally, it is also possible that either or both sexes will show a novelty preference for the novel, neutral eye expressions at the level of 5-month-old females or better. Therefore the current study does not make a specific prediction as to performance at 7 months in terms of a novelty preference to the novel, neutral, eye expression. With respect to facial identity, infants of both sexes are predicted to discriminate the novel face, as they did at 5 months, and no sex difference is predicted due to general improvement in face processing leading to ceiling effects. Finally, the relation between the size of the social environment and face processing, as well as the relation between level of locomotion and face processing were explored, as in Chapter 2.

3.2 Methods

3.2.1 Participants

Twenty two[1] infants were included in the final sample (*M* age = 234.7 days, *SD* = 8.4 days, range 219 to 250 days): 11 females (*M* age = 233.5 days, *SD* = 8.8 days, range 221 to 250

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[1] The original intent was to test 10 infants of each sex, counterbalancing the order of test trials, and matching the number of infants run in the younger group, but due to an infant male video that was thought not to be recorded due to experimenter error, and was later found, and an additional female infant run, the final sample included two additional infants, leading to a slightly imbalanced counterbalancing, with one of the orders (NE NE F F) having 6 infants of each sex compared to 5 infants of each sex in the other order (F F NE NE).

days), 11 males (*M* age = 235.8 days, *SD* = 8.2 days, range 219 to 250 days). All were first-born, healthy and full term (at least 38 weeks gestation), living in a two parent home. All but 2 of the infants had Caucasian mothers. The two remaining mothers (both mothers of females) were 75% Caucasian 25% Métis, and 50% Caucasian 50% East Indian, respectively, and both were judged to have a Caucasian appearance by a Caucasian experimenter. All but two of the infants had Caucasian fathers, as well, with one additional father 50% Caucasian 50% Latin American (father of a female), and the other Métis (father of a male). Infants were recruited by contact with new parents at the local maternity hospital in Vancouver and by community flyers and referrals. The criterion for being included in the analysis was completing the first 5 of the 6 test trials, with a minimum looking time of 1 second in each. All infants in the final sample completed all 6 test trials. Additional infants were tested but excluded from for the analyses for the following reasons: 4 due to crying (2 males, 2 females), 1 due to the infant not looking for at least 1 second to one of the first 5 test trials (male), 1 due to equipment failure, and 1 due to experimenter error.

3.2.2 Stimuli

The stimuli used for habituation and test were the same stimuli as used in Chapter 2.

3.2.3 Procedure

The procedure was identical to that used in Chapter 2, except for the level of locomotion variable extracted from the questionnaires, as 7-month-old infants exhibit a wider range of locomotion abilities. As in Chapter 2, in the child characteristics questionnaire, parents were asked “What is your child’s current most advanced mode of getting around (no motion, rolling over – to either or both sides, scooting on bum, creeping, crawling, walking, etc.)?” Two motor activity scores were extracted – locomotion (0 – no, 1 – yes), and level of locomotion (0 – no motion, 1 – rolling over, 2 - advancing forward in some way, 3 – creeping/belly crawl, 4 – crawling, 5 – crawling for 2 weeks or longer).

3.3 Results

3.3.1 Habituation phase

Male and female infants did not differ in number of trials to habituation, $t(20)=.706$, $p=.489>.1$ (*M* males=6.55, *SD*=0.93, range 5 to 8; *M* females=6.09, *SD*=0.58, range 4 to 11). In terms of total looking time during habituation, because the female total looking time was positively skewed, a t-test comparing the groups was run on the lg10 of the total looking times. The female mean total looking time during habituation was smaller than the male mean, but the difference only approached significance at the $p<0.05$ level: $t(20)=1.89$, *p* (two-tailed)=.073, effect size (Cohen's *d*)=0.81 (total looking time, non-transformed: *M* males=90.61, *SD*=33.86; *M* females = 66.84, *SD*=35.71). Males displayed longer first looks to the first presentation of the habituation stimulus, $t(20)=2.184$, *p* (two-tailed)=.041, effect size (Cohen's *d*)=0.93 (*M* males=14.51, *SD*=7.8; *M* females = 8.52, *SD*=4.67), and the mean of the longest first look in the habituation phase was larger for the males than the females, $t(15.223)=2.305$, *p* (two-tailed)=0.036 ($p=0.032$ when equal variances are assumed. Equal variances were not assumed since Levene's test for equality of variances produced $F = 8.321$, $p= 0.009$), effect size (Cohen's *d*) = 0.98 (*M* males= 16.06, *SD*=7.62; *M* females=10.05, *SD*=4.09).

To examine the pattern of looking over trials during the habituation phase, a 2 (sex) x 2 (trial type: peak, criterion) mixed-model ANOVA was conducted, with trial type (average looking time on the 3 peak trials, average looking time on the three criterion trials) as the repeated measure. The only significant effect was a main effect of trial type, $F(1,20)=45.57$, $p<0.00001$, $\eta^2_p=0.7$ (*M* looking time on peak trials for males=19, *SD*=9.74, *M* looking time on criterion trials for males=7.33, *SD*=2.86. *M* looking time on peak trials for females=15.47, *SD*=8.78, *M* looking time on criterion trials for females=6.21, *SD*=3.43), consistent with the presence of habituation.

3.3.2 Test Phase

The measure of interest, as in Chapter 2, was the duration of the first look to the first trial of each type. Infants' mean first look duration to the first trial of each test trial type (familiar, novel eye expression, novel face) are shown in Figure 3.1.

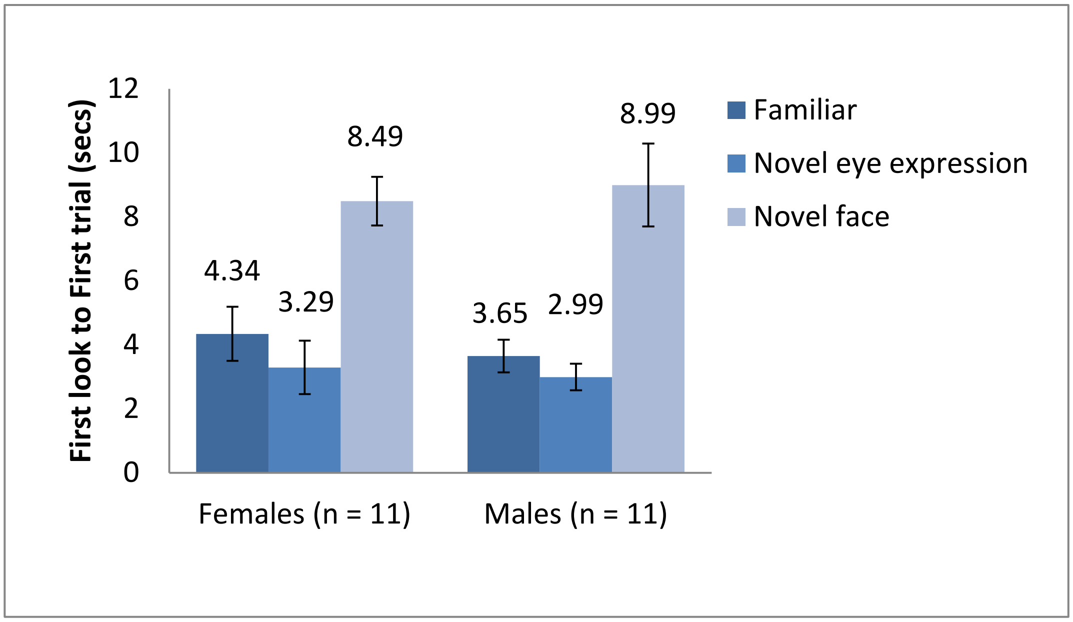

Figure 3.1. Mean first look duration to the first test trial of each type, by sex, 7 to 8 months

Eye expression discrimination

To test whether the ability of 7- to 8-month-old female infants to discriminate between different eye expressions of the same face differs from that of males, as in Chapter 2, an eye expression discrimination score was calculated for each individual by dividing the duration of the infant's first look to the first novel eye expression test trial by the sum of the duration of the first look to the first novel eye expression test trial and the duration of the first look to the first familiar test trial. Figure 3.2 shows the mean eye expression discrimination scores for the two sex groups. The mean discrimination score for 7- to 8-month-old females was M=.415, SD=.143, and the results of a 2-tailed t-test comparing the mean of the discrimination score to chance (0.5) produced a result that approached significance at the p<0.05 level: t(10)=1.974, p (two-tailed)=.077, effect size (Cohen's d)=0.6. For 7- to 8-month-old males, the mean discrimination score was M=.46, SD=0.154, and the results of a 2-tailed t-test comparing the mean of the discrimination score to chance produced t(10)=.925, p(two-tailed)=.377, effect size (Cohen's d)=0.28. Uniting the two sex groups of infants, the mean discrimination score of the 7- to 8-month-old group was marginally different from chance (0.5) at the p<0.05 level, M=.436, SD=0.147, t(21)=2.047, p(two-tailed)=.053, effect size (Cohen's d)=0.44, and the difference between the two sex groups at age 7 to 8 months was not significant t(20)=.661, p(two-tailed)=0.516. A two-tailed Fisher's Exact Test comparing the proportion of the females who had an eye expression discrimination score higher than the chance score of 0.5 (18%) to the proportion of the males who had a discrimination score higher than 0.5 (45.5%) produced non-significant results: *p* (two-tailed)=0.361.

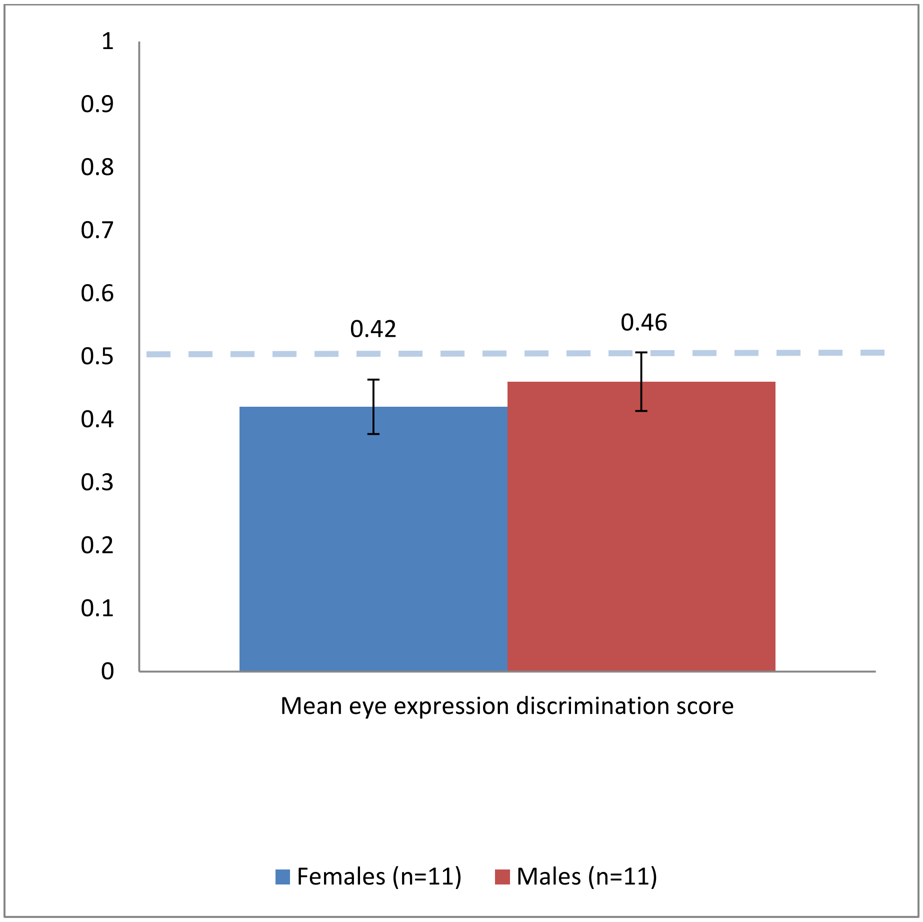

Figure 3.2. Mean eye expression discrimination scores, by sex, 7 to 8 months

Face identity discrimination

A face identity discrimination score was also calculated for each individual, by dividing the duration of the infant's first look to the first novel face test trial by the sum of the duration of the first look to the first novel face test trial and the duration of the first look to the first familiar test trial. Figure 3.3 shows the mean face identity discrimination score for the two sex groups. Both sexes had a mean face identity discrimination score significantly greater than 0.5. For females, *M*=.68, *SD*=.083, *t*(10)=7.177, *p* (two-tailed)=0.00003, effect size (Cohen's *d*)=2.16. For males, *M*=.7, *SD*=.1, *t*(10)=6.463, *p* (two-tailed)=0.00007, effect size (Cohen's *d*)=1.95. A two-tailed t-test comparing the mean face identity discrimination scores of the two sexes did not produce significant results - $t(20)=.422$, p (two-tailed)=.674. On the individual level, 10 out of 11 females and 11 out of 11 males had a face identity discrimination score over 0.5. To sum up, at 7 to 8 months, no effect of sex on discrimination of face identity was found in the current study.

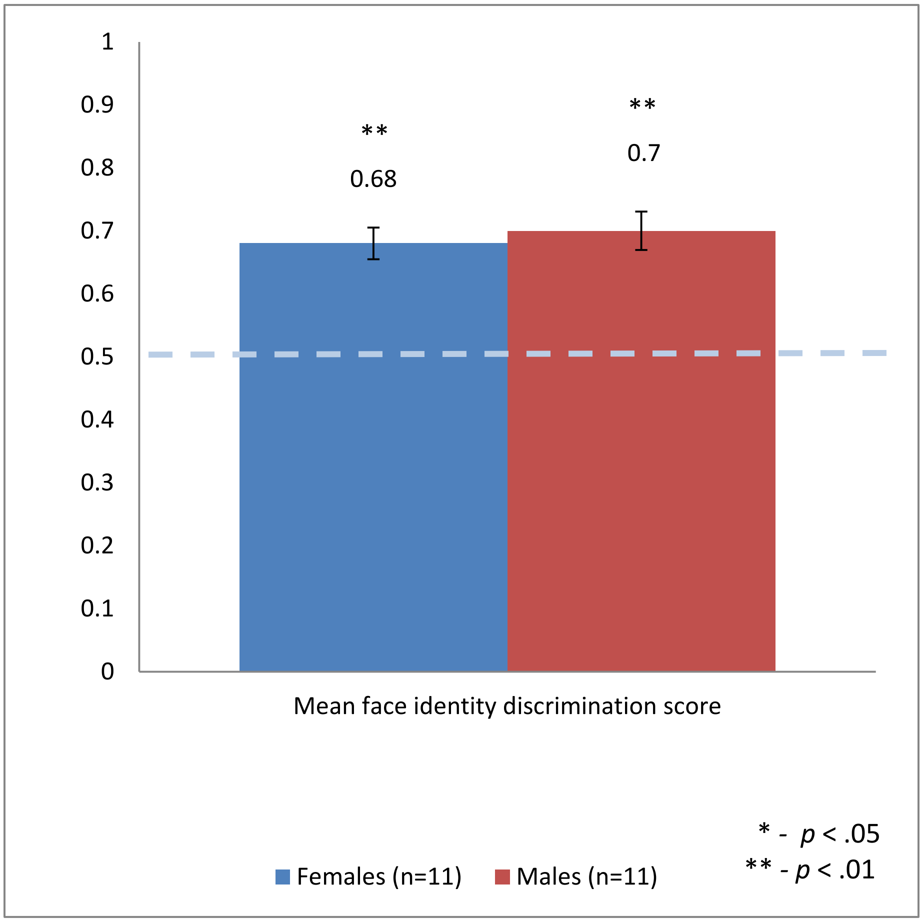

Figure 3.3. Mean face identity discrimination scores, by sex, 7 to 8 months

Relation between social environment and locomotion variables and discrimination for the two sexes

For the exploratory analysis, as in Chapter 2, the relation between the social environment and locomotion variables and discrimination was analyzed for each sex separately, as it is unknown whether these factors influence the discrimination performance of infants of the two sexes in the same way. Due to the low variance of the locomotion variable (with only one female having no locomotion), this variable was not included in the analysis. To look at the effects of social environment and locomotion variables on face discrimination and eye expression discrimination for the 7- to 8-month-old infants, I calculated the correlation of each of the 3 variables (familiar people, familiar adult Caucasian females, locomotion level) with each of the two discrimination scores (face identity discrimination and eye expression discrimination), with Spearman's rank order correlation rather than Pearson correlation used in correlations involving the locomotion level variable since it is an ordinal variable.

The results for the males were: For face identity discrimination, the correlation between number of familiar people and the face identity discrimination score was r=.514, p=.105, and the correlation between number of familiar adult Caucasian females and the face identity discrimination score was r=.542, p=.084. Spearman's rank order correlation between level of locomotion and the face identity discrimination score was r_s=.311, p=.351. Thus the effect of familiar adult Caucasian females approached significance, and less so the effect of familiar people. For eye expression discrimination, none of the correlations were significant. The results of the current study suggest that for males, the social environment has an effect on the response to a novel face, with males who are familiar with a larger number of people and a larger number of familiar adult Caucasian females showing a greater novelty preference, although the results only approached significance. However, since it is unclear whether the change of eye expression which preceded the change to a novel face had an effect on looking time to the novel face, follow up studies should look at the response to a novel face without an intervening change in eye expression.

For the females, for eye expression discrimination and face identity discrimination, none of the variables were correlated at a 0.05 significance level. The only correlation to approach significance was Spearman's rank order correlation between the eye expression discrimination score and level of locomotion, which was r_s=0.538, p=0.088 (see Figure 3.4). The correlation between the face identity discrimination score and familiar adult Caucasian females was r= -.474, p=.141. The correlation between the eye expression discrimination score and number of familiar adult Caucasian females was r= -.183, p=.59.

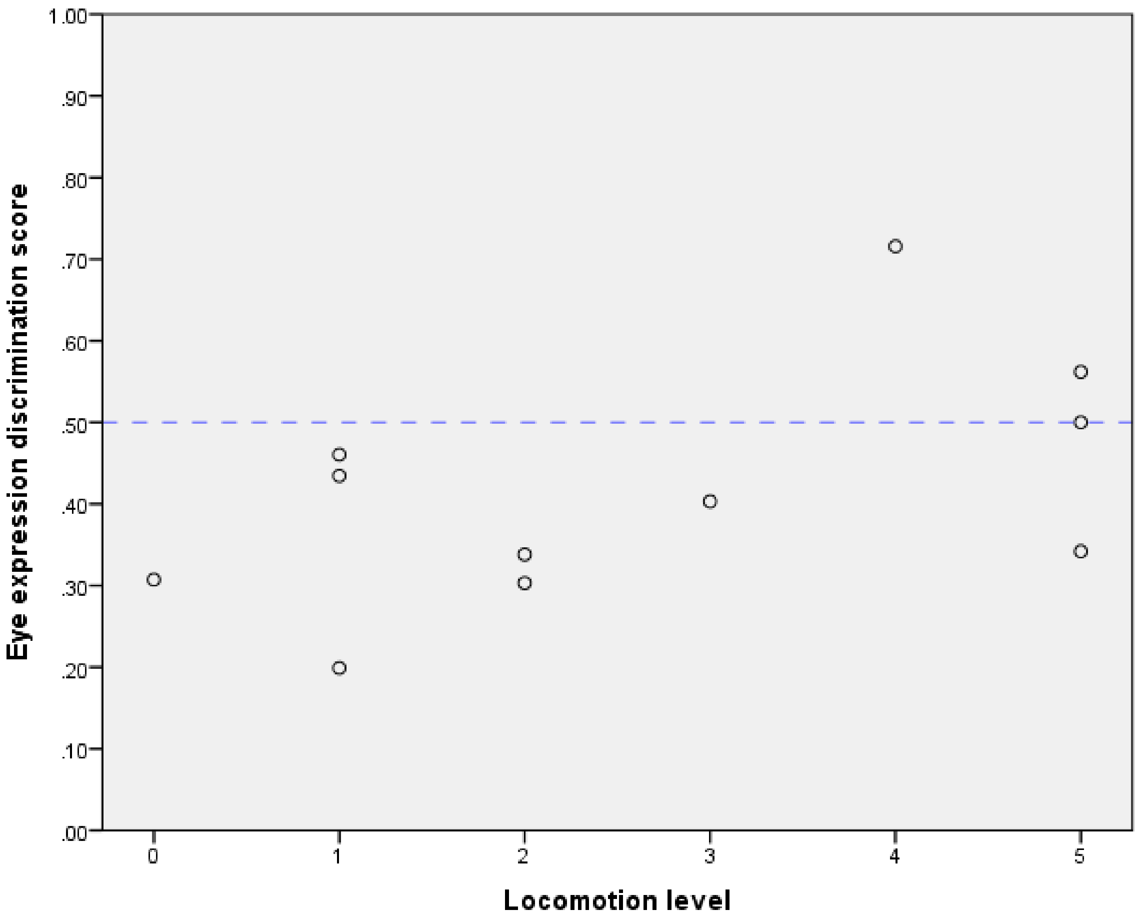

Figure 3.4. Relation between level of locomotion (0: no motion; 1: rolling over; 2: advancing forward in some way but not creep/crawl; 3: creeping/belly crawl; 4: crawling; 5: crawling for 2 weeks or longer) and eye expression discrimination score – 7- to 8-month-old females

3.4 Results – Comparison of age groups (data for younger group obtained in study in Chapter 2)

3.4.1 Habituation phase

To look for differences in habituation parameters over both ages, 2 (sex) x 2 (Age group) ANOVAs were run on all of the habituation variables analyzed in section 3.3.1. For number of trials to habituation, the ANOVA did not produce any significant effects. For total looking during the habituation phase, again with lg10 transformed scores, the ANOVA produced only a nearly significant effect of Age group, $F(1,38)=3.879$, $p=.056$, $\eta^2_p=0.093$. Looking at the graph of the lg10-transformed total looking times in habituation as a function of sex and age (Figure

3.5) revealed this marginal effect was mainly driven by the older females displaying shorter looking times than the younger females. Follow up t-tests confirmed this: for older females compared to younger females, the difference in means of the lg10 transformed total looking times was significant – $t(19)=2.605$, p (two-tailed)=0.017, while for older males compared to younger males the difference was not significant, $t(12.414)=.381$, p (two-tailed)=0.71 with equal variances not assumed (Levene's test $F=9.618$, $p=0.006$), $t(19)=.394$, p (two-tailed) =.698 with equal variances assumed. But for a nearly significant interaction with age for the longest first look in the habituation phase: $F(1,38)=3.645$, $p=0.064$, $\eta^2_p=0.088$, none of the other ANOVAs produced significant effects. However, t-tests comparing the two female groups revealed that older females tended to look for shorter durations than the younger females in other looking time variables as well, and had significantly shorter longest first looks in the habituation phase $t(19)=2.358$, p (two-tailed)=.029 (*M* 5-month-old females=18.01, *SD*=11.54, *M* 7- to 8-month-old females=10.05, *SD*=4.09. t-test run on lg10-transformed looking times).

To examine developmental changes in habituation, a 2 (sex) x 2 (Age group) x 2 (trial type: peak, criterion) mixed-model ANOVA was conducted, with trial type (average looking time of the three peak trials, average looking time of the three criterion trials) as the repeated measure. The main effect of trial type was significant $F(1,38)=93.798$, $p<0.001$, $\eta^2_p=0.712$, consistent with the presence of habituation. The only other significant effect was a between-subjects effect of Age group $F(1,38)=4.125$, $p < 0.049$, $\eta^2_p=0.098$, indicating that the younger infants looked longer at the stimuli than the older infants in both types of trials.

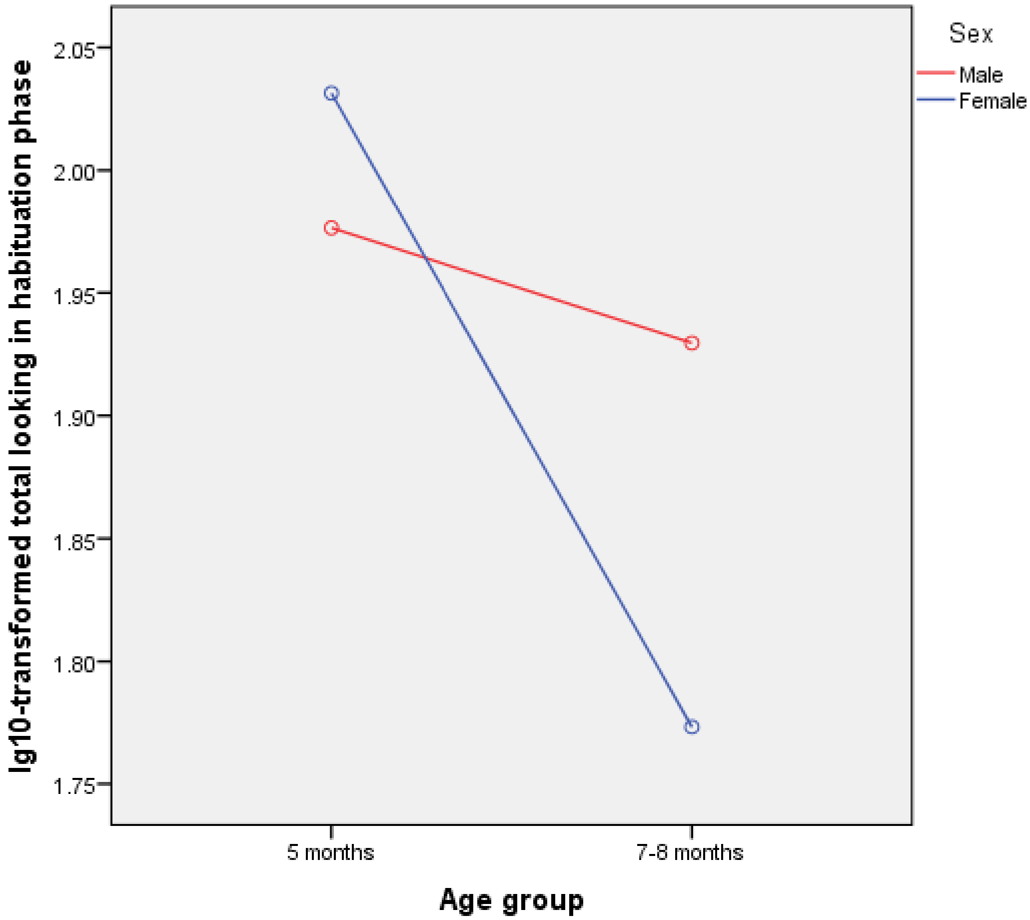

Figure 3.5. Relation between lg10(total looking time in habituation phase) and age for the two sex groups

3.4.2 Test phase

Developmental changes in eye expression discrimination

To test for developmental changes in eye expression discrimination, taking sex into account, a 2 (Sex) x 2 (Age group) Univariate ANOVA was conducted, with eye expression discrimination score as the dependent variable. The ANOVA produced a main effect of Age group $F(1,38)=4.918$, $p=0.033$, $\eta^2_p=0.115$, and an interaction of Age group x Sex, $F(1,38)=4.401$, $p=0.043$, $\eta^2_p=0.104$ – see Figure 3.6 for the relation between age, sex and eye expression discrimination score.

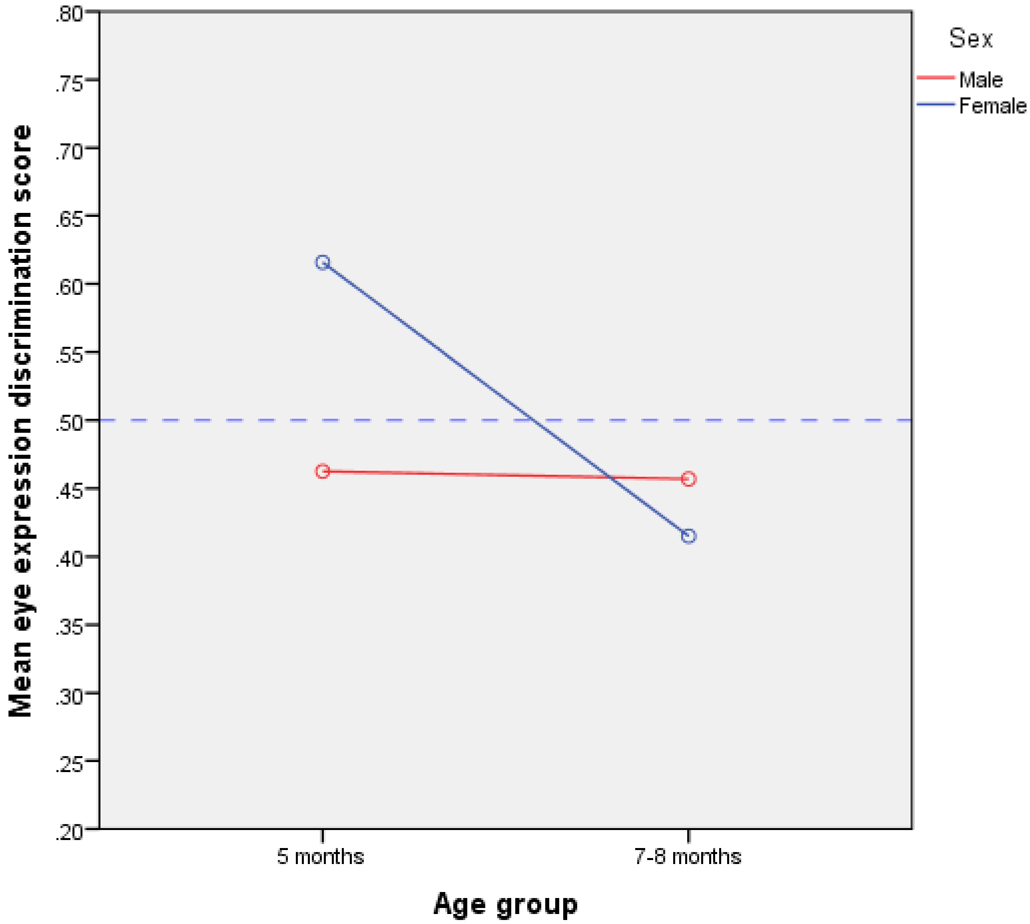

Figure 3.6. Relation between eye expression discrimination and age for the two sex groups

The Age group main effect indicated that, while the younger infants, as a group, looked longer at the novel eye expression trial (neutral eyes) compared to the familiar test trial (smiling eyes), for the older group this was reversed, and looking to the familiar test trial was longer than looking to the novel eye expression trial. To explore the Sex x Age group interaction, as well as to explore the development within each sex group, independent sample t-tests comparing the mean eye expression discrimination scores in the two age groups were run separately for each sex. For the females, the results were $t(19)=2.888$, p (two-tailed)=0.009, effect size (Cohen's d)=1.26 (*M* eye expression discrimination score 5-month-old females=0.62, *SD*=0.18; *M* eye expression discrimination score 7- to 8-month-old females=0.42, *SD*=0.14). For the males, the results were $t(19)=0.09$, p (two-tailed)=0.929, *ns*. Thus, the developmental change was only significant in the female group, with a shift from a novelty preference in the younger group to a familiarity preference in the older group.

Developmental changes in face identity discrimination

To test for developmental changes in face identity discrimination, taking sex into account, a 2 (Sex) x 2 (Age group) Univariate ANOVA was conducted, with face identity discrimination score as the dependent variable. None of the main effects or interactions were significant. To explore the development within each sex group, independent sample t-tests comparing the mean face identity discrimination scores in the two age groups were run separately for each sex. The only significant effect was that Levene's test for equality of variances produced significant results for the male group (F=7.571, p=0.013), with the variance of the 5-month-old males larger than that of the 7- to 8-month-old males (*M* 5-month-old males=0.63, *SD*=0.17; *M* 7- to 8-month-old males=0.7, *SD*=0.1).

3.5 Discussion

In Chapter 2 it was found that 5-month-old females show a novelty preference for a face with a neutral eye expression, following habituation to a face with a smiling eye expression, while males do not. In the current study I explored whether this pattern of sex differences in discrimination remains stable with development in infancy, even after major changes in face processing and in facial expression processing have occurred. As described in the introduction, on the basis of the work to date with respect to the development of the processing of facial expressions and of face processing between the two ages of 5 months and 7 to 8 months, no a priori predictions as to how the data would pattern could be made. The main finding of the current study is the developmental transition between 5 months and 7 to 8 months, from a novelty preference for a change from smiling to neutral eyes, to a familiarity preference, a change that was driven by the female infants, with the males not showing a significant preference at either age, or showing any change with age. Thus, taken together, the results of Chapters 2 and 3 with respect to processing of eye features, at least when eye expressions are concerned, suggest that while females are developing and changing in terms of processing of eye area features, males are not processing the featural information in the eye area at all, at either age. This is further support for the hypothesis that the development of ventral visual processing advances faster in females than in males. Since the change in question was a change in eye expression, this sex difference also has implications for the social development of the two sexes, as males seem to be disregarding information that is socially meaningful, while females are, at the very least, detecting the information, and possibly attributing meaning and/or attaching value to the different eye expressions.

From the results of the current study it is not possible to say whether the only factor involved in the switch from a novelty preference of the 5-month-old females to a familiarity preference of the 7- to 8-month-olds is the switch from a focus on the features to a holistic style of processing and broader scanning which leads to slower processing of the features, without relation to the particular change in the current study from smiling to neutral eyes, or whether the specific featural change is what drove the pattern of results. Future follow up studies could elucidate the matter. If the familiarity preference of the 7- to 8-month-olds was a result of a preference for the smiling eyes over the neutral eyes, as discussed in the introduction, whether due to an interpretation of the expression as smiling, or due to perceiving the half smiling expression as more interesting and unfamiliar, or due to lower level differences such as the smiling eyes being a more complex stimulus, or etc., then an order effect should be found – i.e. if the infants are habituated to the face with the neutral eye expression and presented with the face with the smiling eyes at test, the infants should show a novelty preference. If, on the other hand, the two eye expressions are just perceived as different, and the familiarity preference is due to a slow processing of the features, then a familiarity preference will again be found. A visual preference test between the two stimuli at both ages for both sexes may also serve to elucidate the matter. Additional methods, like ERP (as in, e.g., Grossmann et al., 2006), could also be used to examine whether any emotional tone is attached to the smiling eyes for either sex.

The males in the current study and in Chapter 2 performed similarly with respect to eye expression discrimination, and showed no significant preference at either age. Since the two studies found a developmental change in the performance of females, from a novelty preference to a familiarity preference, it is possible that males undergo a similar developmental change, but that their development is on a different time schedule compared to the females. Thus it would be interesting to test the infants at other ages, e.g. 6, 10 and 12 months, to see if any clear pattern of preference emerges at other points in development. If such a pattern does emerge in males as well, the paradigm used in Chapter 2 and 3 could then be used to test infants at high risk for autism, to see whether their ability to detect a change in eye expression is delayed further, or absent altogether, and whether performance in this task is correlated with a later diagnosis of autism, and thus this paradigm may be used as a simple tool to assist in early diagnosis of autism. Testing at additional ages would also shed more light on the developmental pattern of the females in terms of eye expression discrimination. Combining eye tracking measures with the study could also potentially illuminate the differences in performance between the ages and sexes, as, for instance, attention to the eye area has been associated with better performance with respect to detection of changes in expression (Amso et al., 2010) and detection of subtle, mainly featural changes (Bolhuis et al., 2016). Scanning patterns have also been found to differ between males and females, in infancy as well as adulthood (Rennels & Cummings, 2013), with at least one study (Hall et al., 2010) finding a relation, in adulthood, between female superiority in identifying facial expressions of emotion, and the duration and number of fixations spent scanning the eyes.

Unlike in Chapter 2 with infants aged 5 months, in the current study I did not find any evidence for a difference between males and females in the discrimination of face identity with the stimuli used. Thus, regardless of any possible differences between the two sexes with respect to the way face identity is processed, they were both equally able to detect the change to a novel face, a change that involved external as well as internal changes, and featural as well as configural changes. Although males and females were equally able to detect the change, they may have been using different information in the discrimination. The results of Chapters 2 and 3, in which males did not show any evidence of detecting a featural change in the eye area, support the suggestion that the males were basing their discrimination more on the configural and/or external feature changes, while the females were attending to the features as well. Also with respect to age, the younger infants who discriminated the two faces successfully, may have been basing their discrimination on different information and different processing strategies than the older infants. Sex and age differences in the ability to detect featural changes in the internal features will be explored in Chapter 4.

As in Chapter 2, there was some indication that male infants' ability to discriminate between the two different faces, in terms of the magnitude of their novelty preference, was related to their social environment. The more adult Caucasian females the infant encountered for at least an hour a week, the stronger the novelty response, although in the current study the relation only approached significance. This suggests that, at least for infant males, the development of face discrimination abilities is strongly related to the close social environment. It is not possible to come to any firm conclusions about the relation between the social environment and face identity discrimination in females, since the eye expression change always preceded the face identity change, and detection of the eye expression change may have influenced performance in the face identity change. Nevertheless, the results suggest that face processing in 7- to 8-month-old females is less affected by the close social environment than is the face processing of males, similarly to the findings in 5-month-olds in Chapter 2.

Finally, for the 7- to 8-month-old females, a relation was found between the level of locomotion and eye expression discrimination. A similar relation was found for the 5-month-old females, but in the opposite direction. Whereas at 5 months less mobility led to an enhanced novelty preference, at 7 to 8 months less mobility led to an enhanced familiarity preference. If the shift from a novelty preference to a familiarity preference is the way the development of eye expression processing advances, at least in females, then the relation between eye expression discrimination and locomotion may be seen as moving in the same direction, with less mobile female infants being more advanced in eye expression discrimination. Enhanced face processing may be related to lower locomotion level, for example, due to less mobile infants spending more of their time interacting with their caretakers or other people face to face, thus gaining greater expertise in face processing.

3.6 Conclusion

The current study revealed developmental differences in the processing of eye expressions. These differences were due to the performance of the female infants at ages 5 months and 7 to 8 months, with the males not evidencing discrimination at either age. This is further indication that already in infancy, the visual and social trajectories of males and females are diverging, in particular with respect to obtaining information from the eye area. What may be driving these differences is currently unknown. Motor and social environment factors may come into play, as suggested by the results of the exploration of these two measures in the current study. In addition, if the suggestion that the extraction of emotional tone from faces is learned through a progression from auditory-visual matching of tone, to auditory, to dynamic visual (Flom & Bahrick, 2007; Walker-Andrews, 1997), and then possibly to static visual, is correct, then an intriguing possibility is that the difference between males and females in visual processing of emotions may also be related to differences in auditory and audio-visual speech integration development between the sexes. Further exploration of the interplay between these different factors and developmental trajectories may lead us to a better understanding of human development, of the development of sex differences, as well as of the divergence of developmental trajectories in developmental disorders such as ASD.

4 Sex Differences in Infancy in Feature Processing and Whole Face Processing

4.1 Introduction

Face processing undergoes many developmental changes during the first year of life. The current study is part of a series of studies designed to test whether males and females differ in their visual processing development, and in particular in the development of face processing, during the first year of life. In addition to sex, the studies take an exploratory look at two factors that may have an effect on face processing – motor activity, specifically the development of locomotion, and the social environment of the infant, that is the people with whom the infant is familiar. Two age groups were chosen for the studies – 5 months and 7 to 8 months. These ages were chosen because previous research has found developmental changes in face processing between these two groups. Also, from the aspect of motor development, most infants are not yet able to creep or crawl at 5 months, and their ability to manipulate objects is also limited – thus infants 5 months and younger have the opportunity to spend proportionately more time looking at faces if such faces are around (see, e.g. Jayaraman et al., 2015), making the first 5 months an optimal period for learning from people and about people. Thus my aim is to explore whether at 5 months females have developed face processing abilities that are superior to the abilities of the males, and whether at 7 to 8 months there are any sex differences in the same tasks.

In Chapters 2 and 3 I found that females and males differ in their ability to detect a change in eye expression in the first year of life. There was also a trend towards a sex difference in the ability to detect a change in face identity at age 5 months, but not at 7 to 8 months. However, for the infants who were able to perform the discrimination of face identity – i.e. looked longer to a novel face over the face shown in the habituation phase - the previous studies did not address the question of the information the infants were using to perform the discrimination. The novel face differed from the habituation face in the internal features themselves (i.e. the eyes, the nose, and the mouth), in the configuration of the internal features – that is, the location of the features in the face and the distance between the features – i.e. the second order relations in the face (see Maurer et al., 2002), and in the external features of the face (e.g. chin, hair, ears, head shape) and the relation between the internal and external features of the face. The current study was designed to explore further whether there are differences between males and females at 5 and 7 to 8 months in one of these variables – specifically in the ability to detect a change in the internal features of the face. In addition, as mentioned above, the study continues to explore the relations between the child's face processing abilities and the child's social environment and locomotion ability.

4.1.1 The development of the processing of the internal features of faces

Several studies have looked at the ability of infants to detect a change in internal features, in the two age groups examined in the current study, using different methods and stimuli, though sex differences have not often been examined. Rose et al. (2008) used infant faces as stimuli and a familiarization method in which the familiarized stimulus was presented alongside different novel stimuli until the infant consistently showed a novelty preference larger than 55%, followed by a test phase of side by side test trials of the familiarized stimulus and the stimulus to be discriminated. They used this method to test whether infants could detect a change of the external features of the infant's face to the external features of the face of another infant, and whether the infants could detect a change of the internal features of the infant's face to the internal features of the face of another infant. They found that 4- to 5-month-old infants could only detect a change in external features, and not a change in internal features, while 6- to 7- and 9- to 10-month-olds could detect both types of changes. Besides the special familiarization method used, Rose et al. (2008) also used infants of varying ethnicities as subjects, as well as an infant face as the stimulus, rather than an adult female face as is used in most other studies of infant face processing, with the female face thought to be the kind of face for which infants with a female primary caretaker have the most expertise (see, e.g. Quinn et al., 2002). Thus, although it is not clear how the above factors may have affected discrimination or possible sex differences (sex differences were not found, but sex was not completely balanced, and also may have varied with respect to ethnicity), at least under some conditions, infants at the age range of 4-5 months attend more to external features for face identity discrimination than they do to internal features, while 6- to 7-month-olds are able to use both types of change.

In the Rose et al. (2008) study described above, the change of internal features involved both featural and configurational changes, since the internal features were cut out as one unit from one infant face and inserted into another. Another study (Scott & Nelson, 2006) found that, following 20 seconds of familiarization, 8-month-olds showed a familiarity preference for the familiarized female face over the same female face with its features (eyes and mouth) changed to those of another female, and a novelty preference for the female face with the configuration of its features changed (eyes further from each other and mouth lowered) over the familiarized face. Four-month-olds failed to detect either change. Though the familiarization time may have been too short for the 4-month-olds, this is another indication of a developmental improvement in the detection of a change in features within the age range looked at in the current study. Quinn and Tanaka (2009) manipulated the features in a female face in a somewhat different manner than Scott and Nelson (2006), by changing the size of the features rather than switching them with features from another face. The configural manipulation was similar to the one used in Scott and Nelson - the distance between the eyes or the distance between the mouth and nose were changed. Using these manipulations, it was found that, following familiarization to a female face, infants aged 3 to 4 months and 6 to 7 months were better able to detect configural than featural changes, and were only able to detect a featural change in the eye area, and not in the mouth area. This is in line with Schwarzer et al. (2007) who found that 4-month-olds were bordering on significance in being able to detect a change in the eye area (eyes and eye brows), when the eye area of a male face was changed, following familiarization to the male face, to the eye area of a female face or vice versa (i.e. familiarization to the female face, then eye area changed to that of the male face), but were unable to detect such a change in the mouth. Six-month-olds were able to detect a change in eye area significantly, but were not tested on the ability to detect a change in mouth. When both the eye area and the mouth were switched, 4-month-olds were able to significantly detect the change.

In both the Quinn and Tanaka (2009) and Schwarzer et al. (2007) studies described above, the number of infants in each sex was not equal, and there is no mention of taking sex into account in the statistical analyses. Also, both studies involved both configural changes (changing the size of the feature of the face changes the configuration of the face, as does changing the angle of the brow) and relatively salient changes to the eye area (abnormally large or small eyes, bushy eye brows, etc.), and this may have made the detection of the feature changes easier than in studies in which female features are changed to another female's features, and there is very little configural change. Taken together, the studies above suggest that for 4- to 5-month-olds, as a group, detecting a change in features is a difficult task, especially if the change is not particularly large or salient, while 7- to 8-month-olds are able to detect a change in features.

4.1.2 Sex differences in featural processing in infancy

While studies have not specifically looked at sex differences in detection of featural changes to the face, there is some research evidence that supports the prediction that females detect featural changes better than males. The main evidence comes from research on the different roles the right and left hemispheres play in face processing, starting from infancy, combined with research on sex differences in face processing lateralization. At 4-10 months (de Schonen & Mathivet, 1990), a right hemisphere (left visual field) advantage was found for identification of the mother's face, and the effect was stronger for boys than for girls. Deruelle & de Schonen (1998), using a female face as the stimulus, found that, at these same ages, infants process configural information (a change in the size of the eyes, which was considered a featural change in Quinn & Tanaka, 2009) with their right hemisphere and featural information (eyes from a different female face) with their left hemisphere. Similar findings supporting the view that the right hemisphere specializes in processing configural facial information and the left hemisphere is involved in processing featural information have been reported in other studies with infants (Scott & Nelson, 2006, 8-month-old infants) as well as adult subjects (e.g. Scott & Nelson, 2006; Maurer et al., 2007; but see Hillger & Koenig, 1991; Cattaneo et al., 2014 for evidence that the right hemisphere is also involved in detection of featural changes, at least in adults, when both the eye and mouth features are changed or all 3 internal features are changed, rather than just one feature). There is also additional evidence to support a sex difference in hemispheric lateralization of face processing in adults, with males showing greater right hemisphere lateralization than females (e.g. Proverbio et al., 2006; Godard & Fiori, 2010), suggesting males process mainly configural/holistic information, and not individual features. Taken together, these findings indicate that females may be better than males at using featural information to discriminate between faces, and that this sex difference is already present at 4-10 months.

4.1.3 The current study

In Chapters 2 and 3, using the method of infant controlled habituation, infants were habituated to a female face with a neutral expression but smiling eyes (with the smiling eyes taken from a different picture of the same female). At test the infants were presented sequentially with two trials of the habituation face, two trials of the same face with the original neutral eyes, and two trials of a novel face. In those studies I found that, at both ages, only female infants were able to detect a change of expression in the eyes (with 5-month-old females showing a novelty preference and 7- to 8-month-old females showing a familiarity preference), while both male and female infants were able to detect a change in face identity, which included changes to both external and internal features, and, within the internal features, both featural and configural changes. It is possible that the infants who detected a change in identity, did so on the basis of the external features alone, as in Rose et al. (2008), and/or on the basis of configural information. Therefore, in the current study, I tested whether infants are able to detect the same change in identity, when only the internal features are changed, with minimal configural changes.

To maximize the probability of infants noticing the change in features (similarly to Schwarzer et al., 2007), all internal facial features were changed – eyes, nose and mouth. Following the presentation of the face with the change in internal features the infants were presented with the face from which the novel features were taken, with its original external features and original configuration. Infants who base their discrimination mainly on internal features may show a smaller increase or even no increase in looking time to the novel whole face, since the internal features have already been presented. Thus, in the current study, infants were habituated to the same stimulus as in Chapters 2 and 3 – a female face with a neutral expression but smiling eyes, and were presented at test sequentially with the habituation stimulus, the same habituation stimulus with its features changed (as well as the eye expression, since the eyes were taken from the photo of a female with a neutral expression), and a novel face whose features were the ones used in the feature change (and was the same novel face used in Chapters 2 and 3).

In reminder, in Chapter 2, 5-month-old female infants were able to detect a change in eyes alone, when the eye change involved was a change in expression, and showed a novelty preference to the change. Thus, in the current study it was predicted that 5-month-old female infants would be able to detect the change, since it included a change in the eye area – both of expression and identity – as well as additional changes that may or may not increase their discrimination performance. If 5-month-old female infants are focusing on featural information in the face, whether because of a general tendency to process faces featurally or because the first change, which was a featural change, directed their attention to the internal features of the face, their novelty preference for the novel whole face was predicted to be smaller than in the original study, since the features of the novel whole face are not as novel, having already been presented in the two test trials of the feature change. As for the 5-month-old males, it was predicted that their performance would not be as good as the performance of the females in the feature change. No prediction was made with respect to their performance in the novel whole face trials. This is because, as mentioned, looking time to the novel whole face trials may be affected by the information obtained in the novel feature trials. Thus, if the two sex groups attend differently to the novel feature trials, this may affect their whole face discrimination, though in a way that is difficult to predict – on the one hand, infants who notice the change in features may be more alert to the possibility of a change occurring in the study, and on the other hand, infants who notice the features may find the novel face less novel, and/or be more attuned to the features in the following test trials.

For the older, 7- to 8-month-old groups, no specific differences were predicted. Both groups of infants were predicted to perform both discriminations, since infants have been shown to be able to detect both changes in internal and external features at this age range (e.g. Rose et al., 2008), to perform featural discriminations in female faces (Scott & Nelson, 2006), etc. Since both a change in eye expression and in identity was involved, it was possible that the change in eye expression would lower the older females' discrimination score for the feature change, since in chapter 3, the change in eye expression resulted in a familiarity preference in 7- to 8-month-old females. On the other hand, the smiling eye expression in habituation may have a positive effect on face identity discrimination in infants who attend to the eyes (see, e.g. Turati, Montirosso, Brenna, Ferrara, & Borgatti, 2011; Brenna et al., 2013). Thus no specific hypotheses were put forward for a sex difference in the 7- to 8-month-old group.

4.2 Methods

4.2.1 Stimuli

The stimuli used for habituation and test were color images of two Caucasian female adult faces. Three pictures of the two female faces were used to create the stimuli in the study - two pictures of one of the females (female A) – one with a neutral expression (picture A1), and one with a smiling expression (picture A2), and one picture of the other female (female B), with a neutral expression (picture B). The pictures were taken from the Radboud Faces Database (RaFD), an initiative of the Behavioural Science Institute of the Radboud University Nijmegen (Langner et al., 2010). Adobe Photoshop was used to crop part of the hair of the two females (to increase attention to the internal facial features instead of the hair), to remove noticeable blemishes and scars, and to insert a gray background. Photoshop was also used to create two new pictures. In one of the two new pictures, the eye expression from the picture of female A with the smiling face (picture A2) was inserted into the picture of the same female with a neutral face (picture A1), replacing the neutral eye expression with the smiling eye expression. In the other new picture, the features (eyes, nose and mouth) of female B were inserted into the picture of female A (picture A1), keeping the configuration of the features (i.e. their location and size) as that of the original configuration of the features of female A. The faces were 26 cm high and 19 cm wide (hair included), which were 22.6 x 16.6 degrees of visual angle when viewed from a distance of about 65 cm. The images (including the neck and shoulders) were set against a gray rectangular background of 39 cm high x 37 cm wide. The entire frame was, in turn, set against the black background of the TV, thus effectively flanked by 2 black stripes, one on either side.

Stimuli images:

Figure 4.1. Habituation stimulus/familiar face (F) test stimulus – picture A1 of female A with neutral overall expression, but with the eyes taken from a picture (A2) of the same female smiling. Hair cropped, background gray (with black vertical stripes at the edges of the image when presented on the screen)

Test stimuli (in addition to habituation stimulus, which is the familiar stimulus) –

Figure 4.2. Familiar face novel features (NFT) – picture A1 of female A with neutral overall expression, and features (eyes, nose, mouth) taken from a picture (picture B) of female B.

Figure 4.3. Novel whole face (NWF) - Female B (picture B), neutral expression.

Figures 4.4, 4.5: Test trial order, ordered from left to right (each stimulus presented alone, mid-screen, for 2 consecutive trials) –

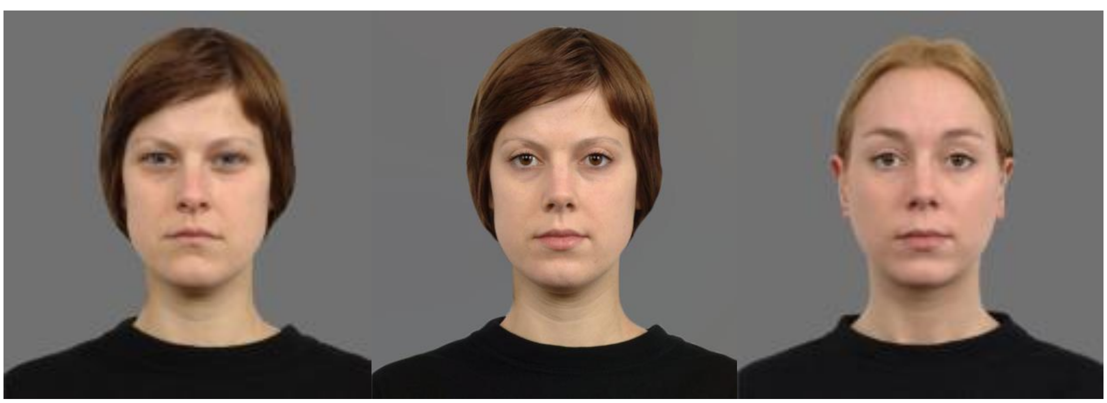

Figure 4.4. Test trial order 1: F NFT NWF

or

Figure 4.5. Test trial order 2: NFT F NWF

4.2.2 Procedure

The procedure was identical to that used in Chapters 2 and 3, except for the replacement of the novel eye expression test trials by the novel features test trials. Each infant was tested in a dimly lit, sound attenuated room. The infant was seated on a parent's lap approximately 65 cm in front of a 32-inch plasma television screen on which the stimuli were presented. To prevent parents from influencing their babies' looking times, the parents' vision was blocked by opaque sunglasses, and they were instructed not to speak or point. A low-light video camera was used to record the infant's face and present it on a computer to an experimenter in another room. The experimenter controlled the study with a computer running the Habit 2002 program (Cohen et al., 2002). The experimenter pressed a button when the infant began fixating the stimulus on the screen, and released the button when the infant stopped fixating the stimulus. The duration of each trial was under the infant's control. Each trial was preceded by 2 seconds of black screen followed by an attention getter which was a static image of a red cross on a gray background, set against the black background of the TV screen. Once the infant fixated the red cross, the stimulus of the trial was presented. The trial continued until the infant looked away for 1.5 seconds (or 120 seconds had elapsed, but no infant reached the 120 second time limit on any trial).

The first trial was a pretest trial, in which the stimulus presented was a photograph of a field of tulips. After the pretest trial, the habituation phase began, during which the habituation stimulus (a neutral face in which the neutral eyes were replaced with smiling eyes) was presented in each trial until the infant's looking time decreased to criterion level. To reach criterion, the infant’s looking time during 3 consecutive trials had to total 50% or less of the peak looking time – the total looking time in the 3 consecutive trials with the longest total looking time up to that point. A sliding window was used, thus the minimum possible number of trials to habituation was 4. The maximum number of trials to habituation was set to 16.

The subsequent test phase consisted of 6 trials - 2 trials with the original image (F – familiar face – neutral face of female A in which the neutral eyes were replaced with smiling eyes), 2 trials with the same image but with different eyes, mouth and nose features (NFT – novel features – the same neutral face of female A as in F, but with the features – eyes, nose, mouth – replaced by those of female B’s face), and 2 trials with a novel whole face (NWF – female B’s face, in a similar pose to the habituation stimulus, and with a neutral expression. Note the eyes, nose and mouth of NWF were the features of NFT). There were two test orders, counterbalanced between infants – F F NFT NFT NWF NWF, and NFT NFT F F NWF NWF. That is, the first 4 test trials were 2 trials with the familiar face followed by 2 trials with the familiar face novel features, or 2 trials with the familiar face novel features followed by the familiar face. These 4 trials were always followed by 2 test trials with the novel face. The test phase was followed by a post-test trial, which was identical to the pretest trial.

Following the test phase, the infant and parent returned to the waiting room. An ethnicity questionnaire was administered to the parent by the experimenter, in which the experimenter interviewed the parent about the people with which the infant is familiar, and their ethnicities. Additional questionnaires, including a child characteristics questionnaire, were administered to the parent, and then the infant received a diploma and a small gift for participating.

The videos recorded during the study were later coded offline frame by frame by a trained coder, at a rate of 29.97 frames per second, for infant looks to and away from the stimulus, and measures of looking time were obtained from this offline coding.

4.3 Study 4.1: Younger group – 5 months

As in Chapter 2, two social environment variables were extracted from the ethnicity questionnaire – number of people the infant meets (besides his or her parents) at least once a week, for at least an hour (familiar people), and number of adult Caucasian females the infant meets (besides his or her mother) at least once a week, for at least an hour (familiar adult

Caucasian females). Regarding motor activity, in the child characteristics questionnaire, parents were asked "What is your child's current most advanced mode of getting around (no motion, rolling over – to either or both sides, scooting on bum, creeping, crawling, walking, etc.)?" Two motor activity scores were extracted – locomotion (0 – no, 1 – yes), and level of locomotion (0 – no motion, 1 – rolling over, 2 – advancing forward in some way).

4.3.1 Participants of Study 4.1

Sixteen infants were included in the final sample (*M* age = 156.6 days, *SD* = 7.6 days, range 146 to 170 days): 8 females (*M* age = 155.6 days, *SD* = 7 days, range 146 to 163 days), 8 males (*M* age = 157.6 days, *SD* = 8.6 days, range 148 to 170 days). As in Chapters 2 and 3, all were first-born, healthy and full term (at least 38 weeks gestation), living in a two parent home. In addition, all were hearing English at least 80% of the time. The language restriction is due to the effect of language on infants' attention to people's faces, since, at least by 6 months, infants prefer to look at faces of individuals the infants have seen speaking their native language – see, e.g., Kinzler et al., 2007 - which may result in different exposure to faces and thus different face expertise in infants with different language backgrounds. Because the focus of this study is on facial features, rather than expression which was the focus of the first two chapters, and because there is a known relation between the faces an infant experiences and processing of facial identity – e.g. in terms of gender and race - the language restriction was added in the current study. All but one of the infants had Caucasian mothers. The remaining mother (of a male) was 50% Caucasian 50% Asian, and was judged to have a Caucasian appearance by a Caucasian experimenter. The same infant's father was 50% Caucasian, 50% Asian, and the rest of the infants had Caucasian fathers. Infants were recruited by contact with new parents at the local maternity hospital in Vancouver and by community flyers and referrals. The criterion for being included in the analysis was completing the first 5 of the 6 test trials, with a minimum looking time of 1 second in each. All infants in the final sample completed all 6 test trials. Additional infants were tested but excluded from the analyses for the following reasons: 5 due to crying (2 males, 3 females), 1 due to parental interruption (female), and 1 due to equipment failure.

4.3.2 Results of Study 4.1

4.3.2.1 Habituation phase

Male and female infants did not differ in number of trials to habituation, $t(14)=.513$, $p=.616>.1$ (*M* males=5.63, *SD*=1.19; *M* females=6, *SD*=1.69), length of first look to the first presentation of the habituation stimulus (analysis was performed on the lg10-transformed looking times to the first presentation, due to skewness), $t(14)=0.353$, $p=0.729$ (non-transformed parameters: *M* males=14.09, *SD*=11.2, *M* females=14.49, *SD*=11.59), or in longest first look in the habituation phase (analysis on lg10-transformed scores due to skewness), $t(14)=.266$, $p=.764$ (non-transformed *M* males=15.02, *SD*=10.98, *M* females=16.78, *SD*=10.4). In terms of total looking time during habituation, the difference between males and females approached significance at the $p<0.05$ level: $t(14)=1.863$, $p=.084<0.1$, effect size (Cohen's *d*)=0.93 (*M* males=121.45, *SD*=54.73; *M* females=78.47, *SD*=35.57).

To examine the pattern of looking over trials during the habituation phase, a 2 (sex) x 2 (trial type: peak, criterion) mixed-model ANOVA was conducted, with trial type (average looking time on the 3 peak trials, average looking time on the three criterion trials) as the repeated measure. The only significant effect was a main effect of trial type, $F(1,14)=30.03$, $p<0.0001$, $\eta^2_p=0.68$ (*M* looking time on peak trials for males=23.66, *SD*=12.16, *M* looking time on criterion trials for males=9.72, *SD*=4.54. *M* looking time on peak trials for females=20.15, *SD*=12.9, *M* looking time on criterion trials for females=8.05, *SD*=3.97), consistent with the presence of habituation.

4.3.2.2 Test phase

As in Chapters 2 and 3, the measure analyzed was the duration of the first look to the first test trial of each type. Infants' mean first look duration to the first trial of each test trial type (familiar, novel features, novel whole face) are shown in Figure 4.6.

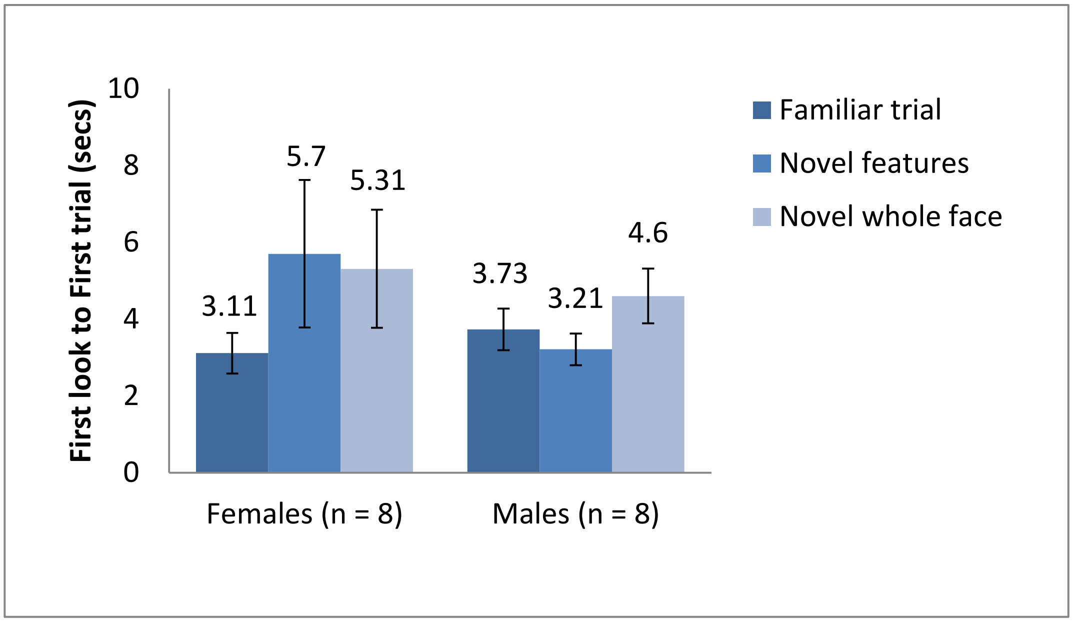

Figure 4.6. Mean first look duration to the first test trial of each type, by sex, 5-month-olds

To test the first hypothesis of the study, whether 5-month-old female infants discriminate internal features better than 5-month-old male infants perform the same discrimination, a feature discrimination score was calculated for each individual by dividing the duration of the infant's first look to the first novel feature test trial by the sum of the duration of the first look to the first novel feature test trial and the duration of the first look to the first familiar test trial. Figure 4.7 shows the mean discrimination score for the two sex groups. Since discrimination is usually inferred by a novelty preference, i.e. a longer duration of looking to the novel feature test trial over the familiar test trial, a one-tailed t-test comparing the mean feature discrimination score to chance (0.5) was conducted on each of the two groups. For females, the mean feature discrimination score was M=0.59, SD=.13, $t(7)$=1.86, p=0.053 (one-tailed), effect size (Cohen's d) = .66, thus their mean discrimination score was marginally significant for being greater than 50%. For males, the mean feature discrimination score was M=0.47, SD=.09, $t(7)$=1.087, p=.84 (one-tailed), *ns*.

It was hypothesized that females would outperform males in feature discrimination, thus a one-tailed independent samples t-test comparing the discrimination score mean of the males to the discrimination score mean of the females was conducted, and its results were: $t(14)$=2.15, p=0.0248 (one-tailed), effect size (Cohen's d) =1.075, that is the female discrimination score mean is significantly greater than the male discrimination score mean, as predicted. A one-tailed Fisher's Exact Test testing whether the proportion of the females who had a feature discrimination score higher than 0.5 (75% of the females) was higher than the proportion of the males who had a discrimination score higher than 0.5 (25% of the males) produced p=0.066<0.1.

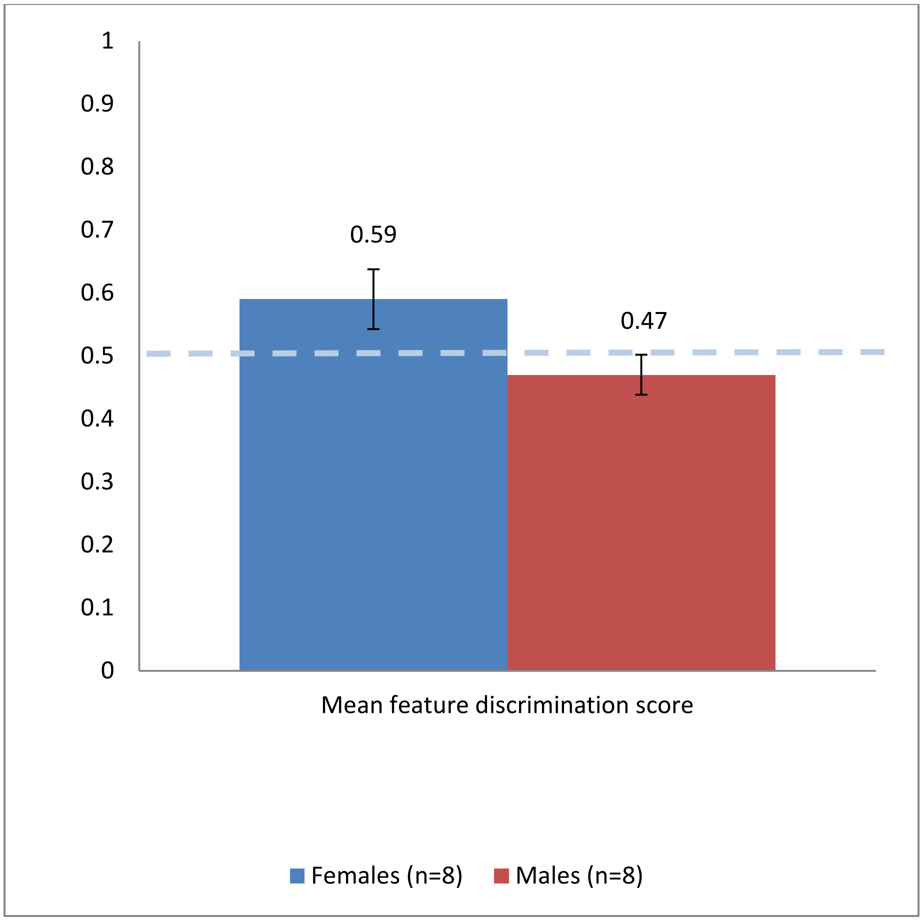

Figure 4.7. Mean feature discrimination scores, by sex, 5-month-olds

A similar discrimination score was calculated for the novel whole face trials, by dividing the duration of the infant's first look to the first novel whole face test trial by the sum of the duration of the first look to the first novel whole face test trial and the duration of the first look to the first familiar test trial. Figure 4.8 shows the mean whole face discrimination score for the two sex groups. In this case, neither sex had a mean whole face discrimination score significantly greater than 0.5, and only as a group, combining both sexes, did the whole face discrimination score approach significance at the 0.05 level for being greater than 0.5. For females, M=.58, SD=.18, $t(7)$=1.279, p (one-tailed)=0.12, effect size (Cohen's d)=0.45. For males, M=.54, SD=.11, $t(7)$=1.111, p (one-tailed)=0.15, effect size (Cohen's d) =0.39. For both sexes together, M=.56, SD=0.14, $t(15)$=1.721, p (one-tailed)=0.053, effect size (Cohen's d)=0.43. A two-tailed t-test comparing the female mean whole face discrimination score to the male mean whole face discrimination score did not produce significant results – $t(14)$=0.476, p (two-tailed)=0.64, *ns*.

The proportion of male and female infants who had a discrimination score above 50% was identical (62.5%).

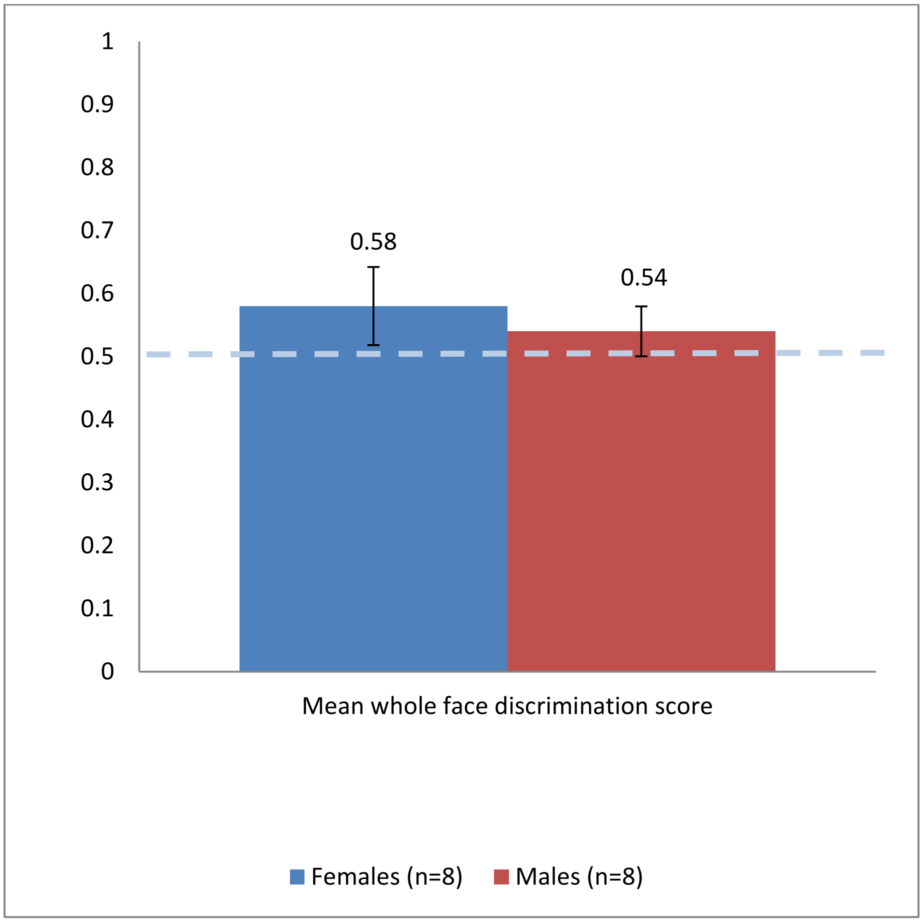

Figure 4.8. Mean whole face discrimination scores, by sex, 5-month-olds

Relation between social environment and locomotion variables and discrimination for the two sexes

For the exploratory analysis, as in Chapter 2, the relation between the social environment and locomotion variables and discrimination was analyzed for each sex separately, as it is unknown whether these factors influence the discrimination performance of infants of the two sexes in the same way. Due to the low variance of the locomotion variable (with only one female having no locomotion), this variable was not included in the analysis. To look at the effects of social environment and locomotion variables on whole face discrimination and feature discrimination, the correlations of the 3 variables (familiar people, familiar adult Caucasian females, locomotion level) with the two discrimination scores (whole face discrimination and feature discrimination) were calculated. As in the previous experimental chapters, Spearman's rank order correlation rather than Pearson correlation was used in the correlations involving the locomotion level variable since it is an ordinal variable.

The results for the males were: For whole face discrimination, the correlation with number of familiar people was bordering on significance at the .05 level – r=.702, p=.052 – see Figure 4.9, while the other correlations were not significant (the correlation with number of familiar adult Caucasian females was r=.308, p=.458). Additional, exploratory, hypothesis generating analyses were also conducted on these data. Interestingly, the infant with a relatively high whole face discrimination score who only knew two familiar people was the only male infant with both parents at home, as both parents were on parental leave throughout his life, which, while only a single subject, is again consistent with the hypothesis that the close social environment is an important factor in male infants' face discrimination abilities. If this infant is dropped from the analysis, the correlation between whole face discrimination and number of familiar people becomes r=.911, p=.004, and the correlation between whole face discrimination and number of familiar adult Caucasian females becomes r=.771, p=.042. For feature discrimination, none of the correlations were significant at the 0.1 level - the correlation with number of familiar people was r=.435, p=.281, the correlation with number of familiar adult Caucasian females was r=.362, p=.378, and Spearman's rank order correlation with level of locomotion was r= -0.504, p=.203. If the infant being reared by both parents is dropped from the analysis, the correlation between feature discrimination and number of familiar adult Caucasian females becomes r=0.808, p=0.028, and the correlation between feature discrimination and number of familiar people is r=.589, p=.164. To sum up, for males, the social environment variables are related to face discrimination, which is in line with my previous findings from Chapter 2.

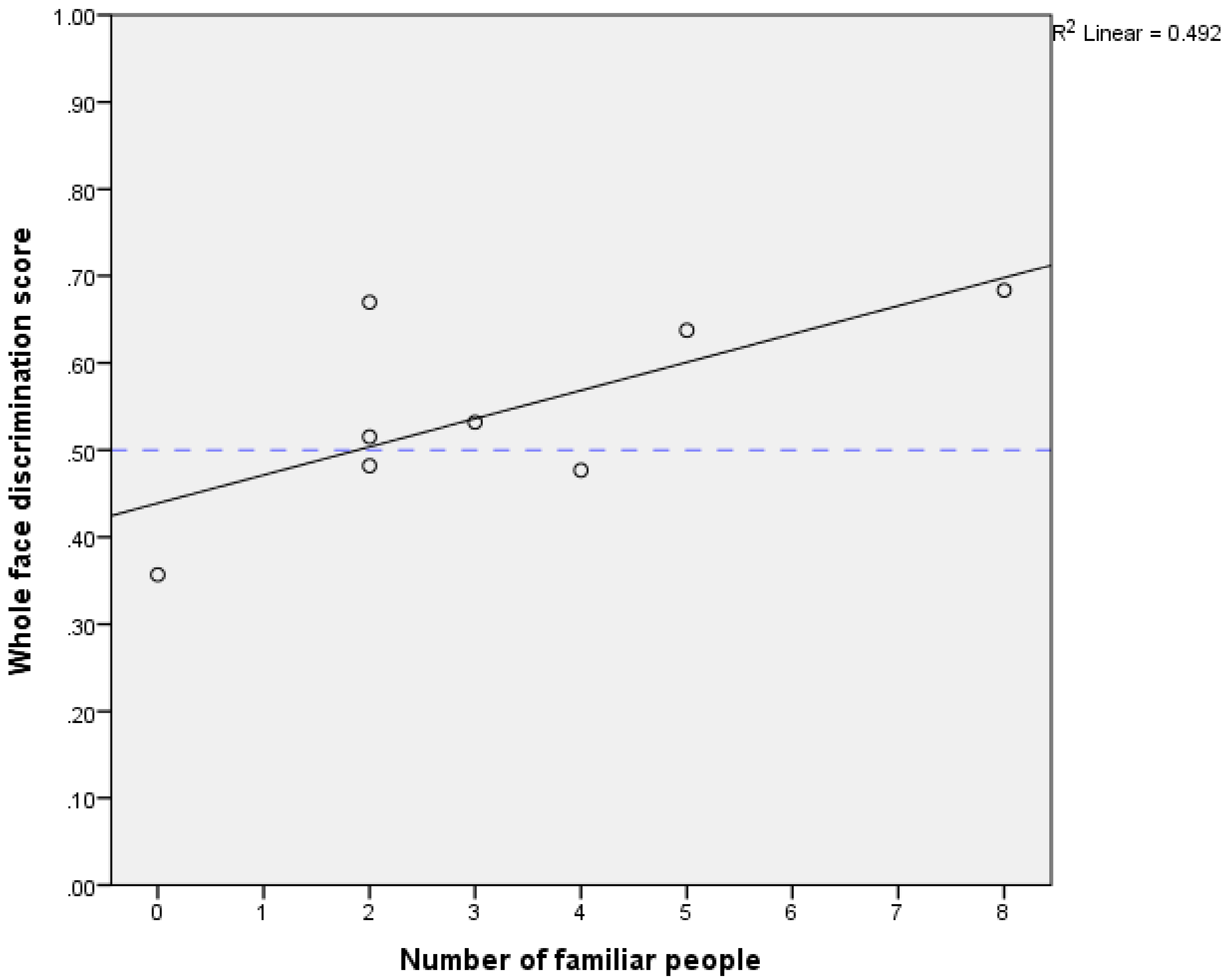

Figure 4.9. Relation between number of familiar people and whole face discrimination – 5-month-old males

The results for females were: For whole face discrimination, the correlation with number of familiar people was r=.544, p=.164, the correlation with number of familiar adult Caucasian females was r=.582, p=.129, i.e. both correlations were positive, but not significant. Spearman's rank order correlation between whole face discrimination and level of locomotion was r_s= -.546, p=0.162 (see Figure 4.10 in the Appendix for the relation between whole face discrimination and number of familiar people, with level of locomotion marked). For feature discrimination, the correlation with number of familiar people was r=.411, p=0.312, the correlation with number of familiar adult Caucasian females was r=.283, p=.497, and Spearman's rank order correlation with level of locomotion was r_s= -.764, p=0.027 – see Figure 4.11 (though note the variance in locomotion level was small in this sample, with only two infants at a locomotion level different from 1, thus these results need to be treated with caution). Thus, for females, there was a significant negative correlation between level of locomotion and feature discrimination. Note that the novel feature face was always shown before the whole face, and since the females detected the novel feature face, this could have an effect of the results of the whole face discrimination and of the correlations involving the whole face discrimination.

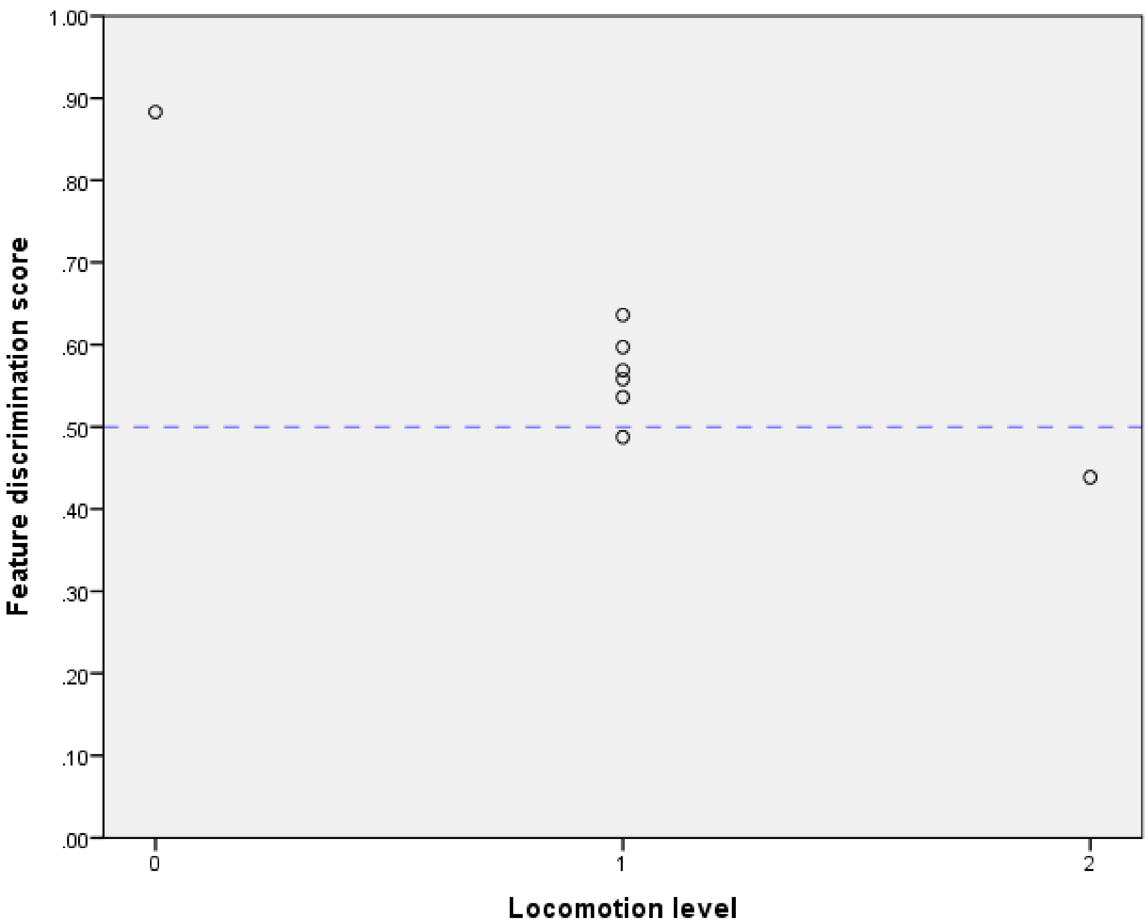

Figure 4.11. Relation between level of locomotion (0 – no motion, 1 – rolling over, 2 – advancing forward in some way) and feature discrimination – 5-month-old females

Comparison of discrimination with eye expression change vs. feature change

Since the habituation procedure was identical to that of Chapter 2, I was able to compare the performance of the infants in the two studies, i.e. compare the performance of the infants who were tested with a change in eye expression (10 in each sex group) to the performance of the infants tested with a change in feature change (8 in each sex group), in both the test trials with the first change (eye expression or feature change, respectively) and in the whole face change. This was done by running two-tailed independent sample t-tests for each sex, on the discrimination scores of eye expression vs. feature change, and on the whole face discrimination scores, comparing the groups from the two studies. For the first change, there was no difference in performance in either sex, that is, adding the change in feature identity did not affect the discrimination performance. For males, the results of the t-test comparing the mean of the eye expression discrimination scores to the mean of the feature discrimination score were $t(16)=.052$, p (two-tailed)=0.959 (M eye expression discrimination score=0.46, SD=0.13, M feature discrimination score=0.47, SD=0.09). For the females the results were $t(16)= .366$, p (two-tailed)=0.719 (M eye expression discrimination score=0.62, SD=0.18, M feature discrimination score=0.59, SD=0.13). However, the initial change (eye expression vs. feature) did have an effect that approached significance on the whole face discrimination performance for the female group. The results of the independent samples t-test comparing the mean whole face discrimination score of the female infants who had been tested with the eye expression change to the mean novel whole face discrimination score of the female infants who had been tested with the feature change were $t(16)=1.928$, p (two-tailed) = 0.072 (M whole face discrimination score for the eye expression change group=0.72, SD=0.14, M whole face discrimination score for the feature change group=0.58, SD=0.18). For the males, Levene's test for equality of variances indicated the variances of the two groups could not be assumed to be equal (F=4.55, p=0.049), and the t-test results comparing the means, with equal variances not assumed, were not significant: $t(15.517)=1.287$, p (two-tailed) = 0.217 (M whole face discrimination score for the eye expression change group=0.63, SD=0.17, M whole face discrimination score for the feature change group=0.54, SD=0.11).

4.3.3 Discussion of Study 4.1

The main finding of study 4.1 is that, as predicted, 5-month-old females are better able than males to detect a change in the features of the face. Since in the current study both the eye expression and the eye identity changed, as well as the nose and mouth identities, it is not possible from the feature discrimination results to determine whether the females based their discrimination on the eye expression alone, as in Chapter 2, or on additional identity information in the eyes, nose, or mouth. However, the decline in whole face discrimination performance compared to that of Chapter 2, suggests that the novel feature face interfered with the discrimination of the novel whole face, whose features were used in the novel feature face. This interference does not necessarily point to the females having encoded the features of the novel feature face and recognized them in the novel whole face, since memory interference for familiar faces is also found when entirely different faces are used as intervening stimuli (see, e.g. Fagan, 1977). It does, however, suggest that the change to novel features had a more detrimental effect on the response to a novel face than the change to a novel eye expression, and thus that females processed more than just the change in eye expression. Taken together, the results of this study and of the study in Chapter 2 suggest 5-month-old females are able to detect both a change in eye expression and a change in the identity of the internal features of the face.

As for the 5-month-old males, even when not only eye expression but also feature identity is involved, and all features are changed, but configural changes are minimal, they are not able to detect the change. Thus, if males were able to perform the detection of the change in eye features in the Schwarzer et al. (2007) study or the Quinn and Tanaka (2009) study, their performance was probably due to either the use of large changes (male to female, small to large eyes), or to the configural changes involved. The 5-month-old males were also not able to detect the novel whole face change in the current study, but it is unclear whether this was a result of interference of the feature face, since the performance of the male infants in Chapter 2 and in the current study did not differ significantly, and since male performance in Chapter 2 was also variable, with only half the males showing a novelty preference above 55%, and with the discrimination performance found to be related to the social environment of the infant.

This brings us to the second set of findings of the current study, those related to the social environment variables and level of locomotion. As in Chapter 2, it was found that for males, face discrimination ability was related to the number of familiar people in the infant's environment, with better discrimination performance in infants with a larger number of familiar people. For females, the correlation between face discrimination ability and the social environment variables was not significant. Level of locomotion, however, was found to be significantly negatively correlated with feature discrimination, with the negative correlation with novel whole face discrimination approaching significance. This is again in line with the findings of Chapter 2, in which face identity discrimination was negatively correlated with level of locomotion in 5-month-old females. Future studies exploring the influence of social environment variables on face discrimination abilities, holding locomotion level constant (e.g. only infants that are rolling over), are needed to elucidate whether the social environment influences face discrimination in females as well. Studies with larger group sizes that have more variability in level of locomotion could elucidate the effect of level of locomotion on face discrimination performance, taking social environment and sex into account, of course.

4.4 Study 4.2: Older group – 7 to 8 months

4.4.1 Materials and procedure

The materials and procedure were identical to those of the younger group. The only difference was in the scoring of level of locomotion (0 – no motion, 1 – rolling over, 2 - advancing forward in some way other than creeping or crawling, 3 – creeping/belly crawl, 4 – crawling, 5 – crawling for 2 weeks or longer).

4.4.2 Participants of Study 4.2

Sixteen infants were included in the final sample (*M* age = 235.7 days, *SD* = 7 days, range 223 to 247 days): 8 females (*M* age = 234.13 days, *SD* = 7.5 days, range 223 to 247 days), 8 males (*M* age = 237.25 days, *SD* = 6.63 days, range 228 to 246 days). All were Caucasian, first-born, healthy and full term (at least 38 weeks gestation), living in a two parent home, and hearing English at least 80% of the time. Infants were recruited by contact with new parents at the local maternity hospital in Vancouver and by community flyers and referrals. The criterion for being included in the analysis was completing the first 5 of the 6 test trials, with a minimum looking time of 1 second in each. All infants in the final sample completed all 6 test trials. Additional infants were tested but excluded from for the analyses for the following reasons: 4 due to crying

(3 males, 1 female), 2 due to missing a test trial (1 male, 1 female), 1 due to parental interruption (female), and 1 due to experimenter error.

4.4.3 Results of Study 4.2

4.4.3.1 Habituation phase

Male and female infants did not differ significantly in number of trials to habituation, $t(14)=1.44$, $p=.173>.1$ (M males=6.38, SD=1.85; M females=7.75, SD=1.98), total looking time during habituation (analysis was performed on the lg10-transformed looking times, due to skewness), $t(14)=1.535$, $p=.147>0.1$, effect size (Cohen's d)=0.78 (non-transformed parameters: M males=71.55, SD=35.61; M females=124.3, SD=79.87), length of first look to the first presentation of the habituation stimulus (analysis on lg10-transformed looking times due to skewness), t(14)=0.079, $p=0.938$ (non-transformed: M males=11.88, SD=8.75, M females=11.38, SD=6.71), or in longest first look in the habituation phase, t(14)=.256, $p=0.8$ (M males=14.96, SD=7.53, M females=15.79, SD=5.4).

To examine the pattern of looking over trials during the habituation phase, a 2 (sex) x 2 (trial type: peak, criterion) mixed-model ANOVA was conducted, with trial type (average looking time on the 3 peak trials, average looking time on the three criterion trials) as the repeated measure. The main effect of trial type was significant, $F(1,14)=19.87$, $p<0.001$, $\eta^2_p=0.59$, consistent with the presence of habituation, while the sex x trial type interaction was not significant: $F(1,14)=2.172$, $p=0.163>0.1$ (M looking time on peak trials for males=14.1, SD=7.06, M looking time on criterion trials for males=6.2, SD=2.99. M looking time on peak trials for females=23.52, SD=17.26, M looking time on criterion trials for females=7.8, SD=3.68).

4.4.3.2 Test phase

As in study 4.1, the measure analyzed was the duration of the first look to the first test trial of each type. Infants' mean first look duration to the first trial of each test trial type (familiar, novel features, novel whole face) are shown in Figure 4.12.

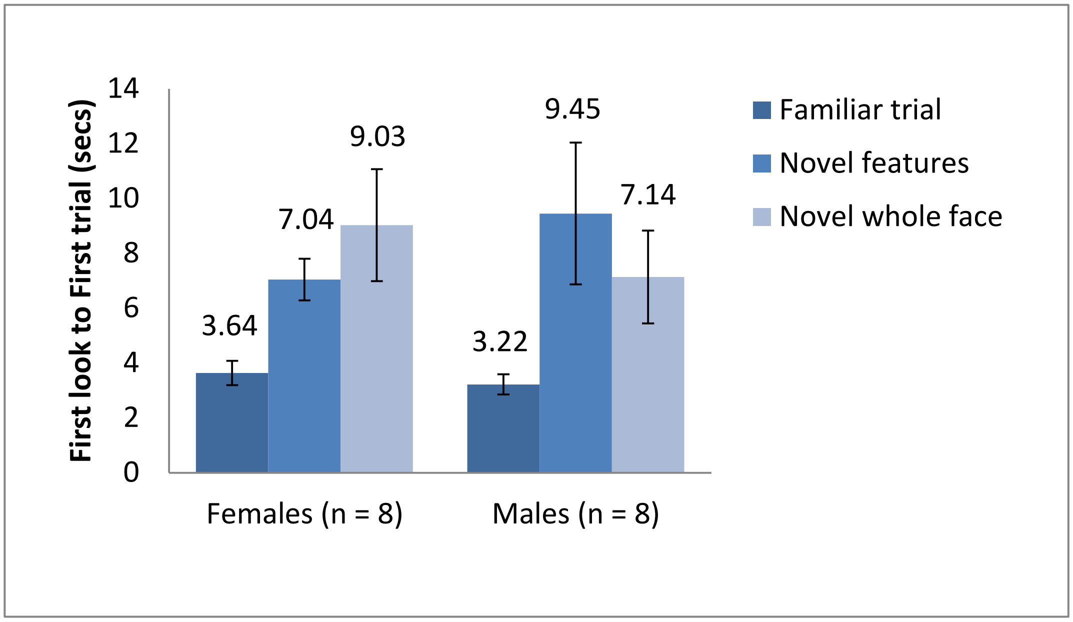

Figure 4.12 – Mean first look duration to the first test trial of each type, by sex, 7-8 months

To test whether female infants discriminate internal features differently than male infants perform the same discrimination, a feature discrimination score was calculated for each individual by dividing the duration of the infant's first look to the first novel feature test trial by the sum of the duration of the first look to the first novel feature test trial and the duration of the first look to the first familiar test trial. Figure 4.13 shows the mean discrimination score for the two sex groups. Since in Chapter 3 and in Scott and Nelson (2006), there was a familiarity preference rather than a novelty preference for changed features in this age group, all tests conducted were two-tailed. A two-tailed t-test comparing the mean feature discrimination score to chance (0.5) was conducted on each of the two sex groups. For females, the mean feature discrimination score was M=0.66, SD=.09, $t(7)$=4.88, p=0.002 (two-tailed), effect size (Cohen's d) = 1.72. For males, the mean feature discrimination score was M=0.67, SD=.18, $t(7)$=2.57, p=0.037 (two-tailed), effect size (Cohen's d)=0.91. Thus for both sexes the mean feature discrimination score was significantly greater than 50%. Comparing the two sexes, Levene's test for equality of variance was significant, F=5.64, p=0.032, with the male variance larger than that of the females. The results of the two-tailed independent samples t-test comparing the feature discrimination score means of the two sex groups, with equal variances not assumed, were $t(10.2)$=0.156, p=0.88, thus the difference in means was not significant. A two-tailed Fisher's Exact Test comparing the proportion of the females who had a feature discrimination score higher than 0.5 (100% of the females) to the proportion of the males who had a discrimination score higher than 0.5 (75% of the males) produced *p*=0.467, *ns*.

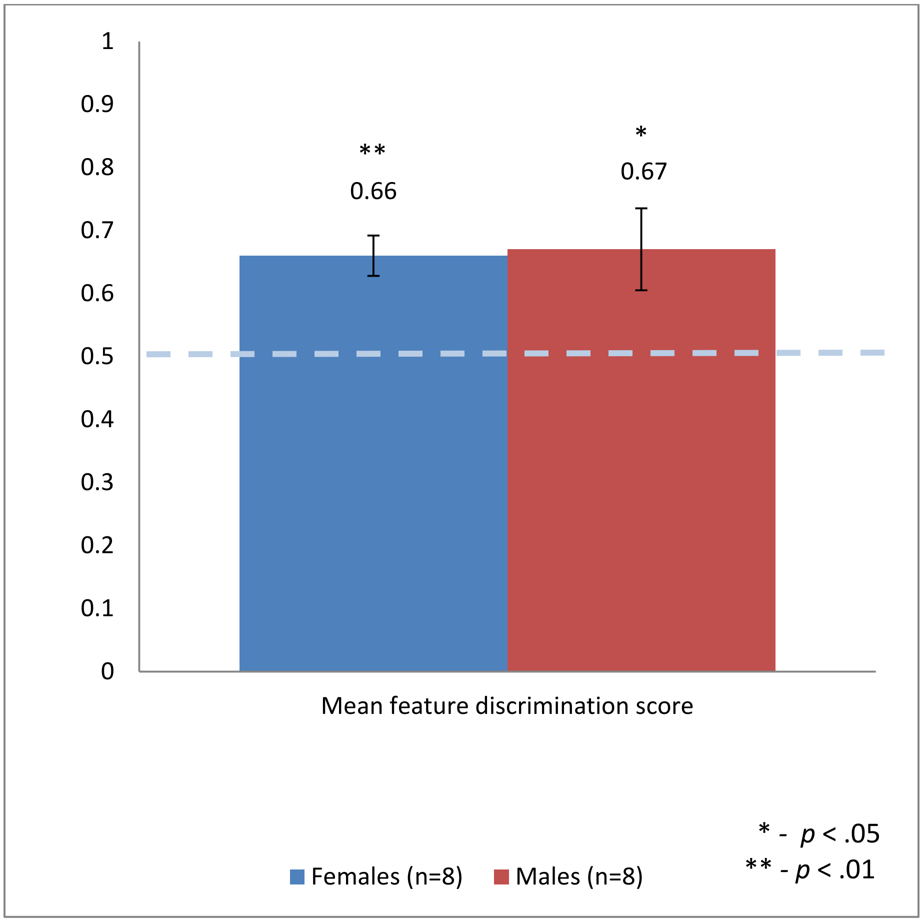

Figure 4.13. Mean feature discrimination scores, by sex, 7- to 8-month-olds

A similar discrimination score was calculated for the novel whole face trials by dividing the duration of the infant's first look to the first novel whole face test trial by the sum of the duration of the first look to the first novel whole face test trial and the duration of the first look to the first familiar test trial. Figure 4.14 shows the mean whole face discrimination score for the two sex groups. A two-tailed t-test comparing the mean whole face discrimination score to chance (0.5) was conducted on each of the two sex groups. Both sexes had a mean whole face discrimination score significantly greater than 0.5. For females, M=.69, SD=.08, $t(7)$=6.19, p (two-tailed)=0.00045<0.01, effect size (Cohen's d)=2.19. For males, M=.65, SD=.13, $t(7)$=3.17, p (two-tailed)=0.016<0.05, effect size (Cohen's d) =1.12. A two-tailed t-test comparing the female mean whole face discrimination score to the male mean whole face discrimination score was not significant – $t(14)=0.689$, p (two-tailed)=0.5, *ns*. A two-tailed Fisher's Exact Test comparing the proportion of the females who had a whole face discrimination score higher than 0.5 (100% of the females) to the proportion of the males who had a discrimination score higher than 0.5 (87.5% of the males) was also not significant, p (two-tailed)=1, *ns*.

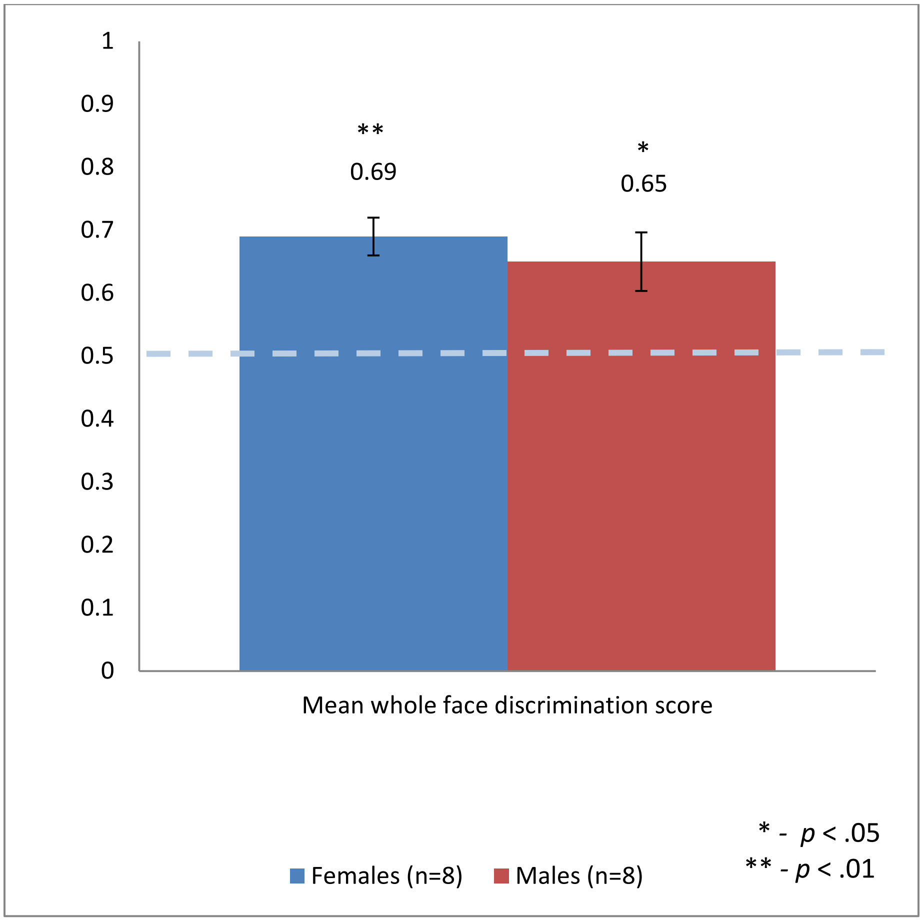

Figure 4.14. Mean whole face discrimination scores, by sex, 7- to 8-month-olds

Relation between social environment and locomotion variables and discrimination for the two sexes

The social environment description was not specific enough to extract the social environment variables for one male and one female, so the social environment variables were analyzed for the 7 remaining males and 7 remaining females. For locomotion, all of the infants but one female had some form of locomotion, so this variable was not included in the analysis. To look at the effects of social environment and locomotion variables on whole face discrimination and feature discrimination, the correlations of the 3 variables (familiar people, familiar adult Caucasian females, locomotion level) with the two discrimination scores (whole face discrimination and feature discrimination) were calculated. The correlations with the social environment variables were performed on the 7 infants in each group with available data, while the correlation with level of locomotion was performed on the groups in their entirety, since locomotion data was available for all infants, with Spearman's rank order correlation rather than Pearson correlation used in correlations with the locomotion level variable since it is an ordinal variable, as in the previous chapters.

The results for the males were: For whole face discrimination, the correlation with number of familiar people failed to reach significance r=.668, p=.101, and the correlation with number of familiar adult Caucasian females was also not significant, but was between .05 and 0.1 - r=.698, p=.081 – see Figure 4.15 in the Appendix. However, in both cases the results seem to have been driven by the same 2 extreme scorers - one with a high discrimination score, one with a low discrimination score - while the rest of the infants had discrimination scores that were similar to each other. Spearman's rank order correlation between whole face discrimination and level of locomotion was r_s= .026, p=.952. For feature discrimination, none of the correlations were significant. The correlation with number of familiar people was r=.107, p=.819, the correlation with number of familiar adult Caucasian females was r=.520, p=.232, and Spearman's rank order correlation with level of locomotion was r_s= -.309, p=.457. To sum up, these exploratory results fail to yield convincing evidence that for 7- to 8-month-old males, the social environment or locomotion variables are related to face discrimination.

The results for 7- to 8-month-old females were: For whole face discrimination, the correlation with number of familiar people was r=.433, p=.332, the correlation with number of familiar adult Caucasian females was r=.556, p=.195 (see Figure 4.16 in the Appendix for the relation between number of familiar adult Caucasian females and whole face discrimination, with locomotion marked). Spearman's rank order correlation between whole face discrimination and level of locomotion for the 8 7- to 8-month-old females was also not significant: r_s= -.439, p=.276. For feature discrimination, the only variable that approached significance at the 0.1 level in females was number of familiar people: r=.631, p=0.129 (see Figure 4.17 in the Appendix).

Thus, for the 7- to 8-month-old females as well, the exploratory results also did not provide evidence that the social environment or locomotion variables are related to face discrimination.

Comparison of discrimination with eye expression change vs. feature change

In Chapter 3, both sex groups of 7- to 8-month-olds showed a mean familiarity preference, though only the females did so at a level that approached significance. Comparing the discrimination performance of the eye expression change to the feature change resulted in a significant difference in both sexes, since in the current study both sexes showed a significant novelty preference. For the females, the results of an independent samples t-test comparing the mean eye expression discrimination score of the 11 7- to 8-month-old females in Chapter 3 to the mean feature discrimination score of the 8 7- to 8-month-old females in study 2 were $t(17)=4.183$, $p=0.0006<.001$ (M eye expression discrimination=0.42, $SD=0.14$, M feature discrimination=0.66, $SD=0.09$). For males the results of the t-test were $t(17)=2.706$, $p=0.015$ (M eye expression discrimination=0.46, $SD=0.15$, M feature discrimination=0.67, $SD=0.19$). There was no difference in whole face discrimination between the two studies, for either sex group. For females, the results of the independent samples t-test comparing the whole face discrimination scores between the two studies were $t(17)=0.145$, $p=0.877$. For males, the results of the t-test were $t(17)=0.924$, $p=0.369$.

4.4.4 Discussion of Study 4.2

In the current sample of 7- to 8-month-old infants, both male and female infants were able to perform both the feature discrimination and the whole face discrimination, and their mean discrimination scores did not differ significantly. Thus, from the current sample it can only be said that 7- to 8-month-olds are able to notice both the featural changes of the internal features and the whole face change, and that detection of the featural changes is not detrimental to the whole face discrimination at this age. As mentioned in the introduction, the effect of using smiling eyes in the habituation stimulus on the discrimination performance in the current study is not known. Since in Chapter 3, the 7- to 8-month-old female infants showed a familiarity preference, and preferred to look at the smiling eyes over a novel neutral eye expression, it is possible that discrimination scores in the current study would have been higher had a neutral eye expression been used in the habituation stimulus. Using a stimulus with a neutral expression as the habituation stimulus could also affect the two sexes differently. Thus, future studies should look at the sex difference without involvement of expression, and perhaps with larger sample sizes.

Regarding the social environment variables, the current study failed to provide convincing evidence for a relation between the social environment variables and face identity discrimination for either sex at the age of 7 to 8 months. However, for the males, the correlation of whole face discrimination did pattern in the same direction as that in Chapter 3, with a larger social environment correlated with better whole face discrimination. In both studies the change to the novel face followed a previous change to the facial features (either eye expression or all features replaced), and may have had some influence on the discrimination scores of some of the infants, and thus on the correlation. Thus, follow up studies in which there is no intervening stimulus are needed to clarify the nature of the relation between face identity discrimination and the social environment in 7- to 8-month-old males. For females, in the current sample, none of the correlations with social environment variables were significant at the $p<0.1$ level, nor were the correlations with level of locomotion. This is also consistent with the findings of Chapter 3, in which the only relation to approach significance for 7- to 8-month-old females was the relation between eye expression and level of locomotion, while face identity discrimination did not correlate with either level of locomotion or the social environment.

4.5 General discussion

The studies in the current paper are further indication that at least some aspects of face processing, namely those that involve a change in features, develop faster in females than in males. In study 4.1, at 5 months, females outperformed males in detecting a change in the features of the face (eyes, nose, and mouth). This is in line with the findings in Chapter 2, in which 5-month-old females outperformed males in detecting a featural change in eye expression. Taken together, the findings of the two studies suggest that, as hypothesized, at 5 months, females are attending to, processing and retaining the details of the internal features of the face more than males, whether only the eyes or all internal features are changed. The 5-month-old males in Chapter 2, who, as a group, did detect the change to a novel face, were thus likely basing their discrimination on the change in external features or in the configuration of the features rather than the change to the internal features themselves.

Following the presentation of the face with a change in internal features in study 4.1, the novel features were then presented in their original configuration, with different external features (i.e. the face from which the novel features were extracted was presented). Unlike in Chapter 2, neither males nor females were able to detect the changes in terms of showing a novelty preference for the novel whole face over the familiar face. For the females, the mean novelty preference for the novel whole face in the group of females in the current study approached significance for being different than the mean novelty preference for the novel whole face in Chapter 2, and the difference was in the predicted direction – the previous exposure to the features of the novel whole face reduced the discrimination. This indicates the intervening novel feature stimulus had a more deleterious effect on the processing of the novel whole face identity than the intervening novel eye expression stimulus, and thus that the 5-month-old females may have processed and retained more than just the eye expression change in the novel feature face compared to the familiarization face. This leads me to conclude that 5-month-old females are able to detect both featural changes in expression and featural changes in identity – i.e., they are able to detect featural changes to the internal features in general. For the males, the novelty preference for the novel whole face did not differ between the males who were first presented with a change in eye expression vs. the males who were first presented with a change in features. This, together with the null preference for the changes in eye expression in Chapter 2 and in features themselves in study 4.1, provides no indication (from Chapter 2 or Study 4.1) that 5-month-old males are able to detect a featural change in either eye expression or in the identity of the 3 internal features. These results are in line with the hypothesis that ventral visual processing develops more quickly in females than in males.

By the age of 7 to 8 months, both sexes are able to detect both changes (featural followed by configural + external), and at least in the current sample do not differ significantly in their ability to perform these discriminations. In the current study, as mentioned above, the change in features involved an eye expression change as well as a feature identity change. Comparing the performance of the 7- to 8-month-old females in Study 4.2 to the performance of the 7- to 8-month-old females in Chapter 3 suggests the females in Study 4.2 responded to more than just a change in eye expression when the internal features were changed, since the discrimination scores in the two studies were significantly different, and there was a shift from a familiarity preference when only the eye expression changed to a novelty preference when the features changed. For the males, the pattern of results changed from a null preference for an eye expression change to a novelty preference for a change in features. Thus, at 7 to 8 months, both males and females are able to detect a change in the identity of the internal features of a face, when the external features are held constant, above and beyond any ability to detect a change in eye expression.

Notably, from the current study it cannot be deduced which changes in features, or in combinations of features, the females and males used to perform the discrimination, and whether they used the same information. Future studies should alter the different features parametrically - eyes, nose, mouth, and combinations of pairs of features, to see which changes are discriminable by either sex at either age, and whether, for instance, 7- to 8-month-old females have an advantage in detecting a change in eye features in general, not only eye expression. As mentioned in the discussion of Study 4.2, using a stimulus with a neutral expression as the habituation stimulus would eliminate the issue of 7- to 8-month-old females possibly preferring a smiling eye expression, and may elucidate further whether there are any differences in the detection of a change in features between the 2 sexes at 7 to 8 months.

The two studies in the current paper, in combination with the studies in Chapters 2 and 3, indicate the need for further examination of the development of face processing in the two sexes, since infant sex was found to significantly affect the development of face processing. Future studies should perhaps use larger sample sizes, since in some cases male performance was more variable and effect sizes and significance levels were lower than for females, but there was not enough power to detect any statistically significant difference between the sexes that might exist. Using an eye tracker in conjunction with habituation studies may add to the understanding of the differences between the two sexes, as sex differences in scanning patterns, starting from infancy, have also been found (Rennels and Cummings, 2013), but their relation to discrimination performance in the two sexes has not been tested, to my knowledge.

The motor development factors and social environment factors provided additional information about the way face processing develops in the two sexes. As in Chapter 2, the near social environment (number of familiar people, number of familiar Caucasian females) was shown to affect face identity processing in the 5-month-old male group. For 5-month-old females, locomotion development seemed to affect discrimination performance (with lower performance in detection of featural change correlated with greater motor development). Although in study 4.1 the female variance in locomotion level was small, these results are in line with the results of Chapter 2, in which face identity discrimination was related to locomotion development for 5-month-old females as well. The exploratory findings for the 7- to 8-month-old groups in study 4.2 were also in line with the findings of Chapter 3, and the two studies taken together suggest that for the 7- to 8-month-old males, as in the case of the 5-month-old males, the social environment influences face identity discrimination. The pattern of results in Chapters 2 through 4 points to a need to take such factors as motor development and social environment into account when looking at face processing development, individual differences, and sex differences in face processing development. As mentioned in Chapter 2, the influence of social environment and motor factors, as well as sex differences in development, may also help clarify and explain the development of face processing in autism, and the factors that contribute to this development.

4.6 Conclusion

The development of the ability to detect featural changes in the internal features of the face progresses differently in females and males. While females showed evidence of this discrimination at 5 months, males can only do so at 7 to 8 months. Motor development and social environment factors also come into play when looking at the face processing capabilities of infants of both sexes. The current paper, together with Chapters 2 and 3, point to a need for more research on sex differences in face processing in infancy, taking factors such as ethnicity, social exposure, motor development, and language into account. Only by looking at the developmental trajectories in combination with each other will we be able to understand the origin of the sex differences in face processing, the development of face processing in general, and perhaps also obtain knowledge as to what may go awry in populations with developmental difficulties in face processing, such as individuals with ASD.

5 Mirror Image and Eye Expression Discrimination in 5-Month-Olds

5.1 Introduction

Sex differences in attention to, response to, and processing of certain types of visual stimuli, have repeatedly been reported. In addition, studies have shown that some sex differences in visual processing and/or manipulation of visual objects in mind are already present in early infancy, at least by the age of 5 months – among them the ability to mentally rotate objects and certain aspects of face processing, such as processing of eye expression (see below). Tests of mental rotation, however, usually, including in the studies with infants which found a sex difference, rely on the ability of the subject to differentiate between an object and its mirror image, and to recall which of the two had previously been presented. Thus, it is possible that a failure of female infants in such tests of mental rotation actually stems from a failure to retain the original image in mind, separately from its mirror image. Since an object is united with its mirror image in the later stages of ventral stream processing (see section 5.1.1), a visual processing strategy that tends to favor ventral over dorsal stream processing, or a more developed ventral processing stream, may cause failure to discriminate between a familiarized object and its mirror image. Face processing, and feature processing in particular, are also abilities related to the ventral stream, thus a more developed ventral stream or a ventral processing strategy, i.e. one that focuses on features and details rather than on gross shape or on location of objects in space, could also lead to better face discrimination and eye expression discrimination.

The current study is part of a series of studies looking at various aspects of visual processing thought to be performed by the ventral stream, to test whether male and female infants differ in the development of the ventral stream, with females showing more advanced development. Thus, the current study aims to test whether the same 5-month-old males and females differ in both abilities, the ability to discriminate between an object and its mirror image, and the ability to discriminate between two eye expressions that differ only in featural information, and whether there is a relation, within infants, between these two abilities – i.e. whether infants who are relatively good at discriminating between an object and its mirror image are relatively bad at discriminating eye expressions, and vice versa. In addition, this study, as in the previous chapters of this thesis, takes an exploratory look at two factors that may have an effect on face processing – locomotion, and the social environment of the infant, that is the people with whom the infant is familiar.

5.1.1 The dorsal and ventral visual streams

There is substantial evidence pointing to two visual processing pathways, specialized for different types of processing – the dorsal and ventral visual streams (see, e.g. Ungerleider & Mishkin, 1982; Ungerleider & Haxby, 1994; see review in Johnson et al., 2001). The ventral pathway, or the "what" or "perception" pathway, extends from the primary visual cortex through to the temporal cortex, ending in the inferior temporal cortex. The dorsal pathway, or the "where" or "action" pathway, extends from the primary visual cortex to the parietal cortex. The ventral stream has been proposed to deal with object identification (Ungerleider & Haxby, 1994). In the ventral stream, the visual scene is processed in detail and more slowly than the dorsal stream (Johnson et al., 2001). Ventral stream processing is sensitive to shape, color, and other surface properties of objects, such as texture (Livingstone & Hubel, 1988). The dorsal stream has been proposed to process the spatial organization of objects – it processes spatial aspects of stimuli, such as direction of motion and velocity, and analyzes the spatial relations between objects and their locations in space (Ungerleider & Haxby, 1994). Goodale and Milner (1992) suggested a somewhat different distinction between the streams – that the ventral route was the vision for perception pathway, while the dorsal stream was the vision for action, or "how", pathway, mediating the required sensorimotor transformation (sensory information to motor coordinates) for visually guided actions on objects. In addition to location and motion, the dorsal stream processes size, coarse shape and orientation (Jeannerod, 1988; Murata et al., 2000).

Both streams have a hierarchical representation. Cells further along the stream respond to more and more complex clusters of features (Ungerleider & Haxby, 1994). In the ventral stream, this includes face recognition cells in the fusiform face area (see Kanwisher & Yovel, 2006). Certain areas of the dorsal stream are sensitive to global motion, rotation, or motion in depth (Ungerleider & Haxby, 1994).

One particular property of the final stages of the ventral processing pathway is a lack of sensitivity to mirror images, that is a unification of an object and its mirror image. In adult macaques, inferotemporal lesions disrupt the ability to distinguish between two different 2D shapes but facilitate discrimination between a shape and its mirror image (Walsh & Butler, 1996). This phenomenon, of a dissociation between the ability to identify objects and the ability to distinguish between an object and its mirror image, has also been found in neuropsychological studies in humans (e.g. Davidoff & Warrington, 1999, Warrington & Davidoff, 2000). In one study (Warrington & Davidoff, 2000), a patient's ability to discriminate between mirror image rotations was dependent on her inability to identify the object. This suggests that processing in late stages of the ventral stream unites an object and its mirror image (see Davidoff & Warrington, 2001). Indeed, in fMRI studies (e.g. Dilks et al., 2011) it was shown that later stages in the object processing hierarchy are not sensitive to mirror image distinctions. Both 3- to 4-month-old infants (Bornstein et al., 1978) and children (e.g. Cronin, 1967) have been found to be susceptible to mirror-image confusion, presumably through the same mechanism of a ventral stream unification of an object and its mirror image. Thus, infants who have a less developed ventral visual system, who process more slowly, or do not process the object fully through the ventral stream, are expected to distinguish between mirror images of a familiarized object, while the faster/better ventral processors are expected not to distinguish between the object and its mirror image.

5.1.2 Sex differences in mental rotation and mirror image discrimination

One area in which sex differences have consistently been found is mental rotation (Voyer et al., 1995), with males showing superior performance. Four recent studies have shown similar differences between male and female infants in the pre-mobile, pre-object manipulation period. Three- to four-month-old males familiarized with a 2D shape (figure 1 or its mirror image) in different rotated orientations showed a novelty preference for the mirror image of the shape, while females did not (Quinn & Liben, 2008), and the same sex difference was replicated with 6- to 7- month-olds and 9- to 10-month-olds (Quinn & Liben, 2014). Five-month-old males habituated to a 3D figure rotating in a certain angle preferred to look at the mirror image of the figure rotating in the complementary, unseen, angle vs. the original figure rotating in the same unseen angle, while females did not (Moore & Johnson, 2008), with a familiarity preference (a preference for the original object over its mirror image) found in 3- to 4-month-old males, but not in females (Moore & Johnson, 2011). As mentioned above, the ability to distinguish between an object and its mirror image is eliminated in late stages of the ventral visual stream. Whether due to deeper processing by the ventral stream or to other factors, such as an inability to retain the form of the familiarized object, it is possible that the results in young infants are not related to mental rotation, but to the ability to distinguish between an object and its mirror image. There is prior evidence for mirror image confusion in infants by the age of three to four months (Bornstein et al., 1978) – however, there is no mention of analysis by sex in that study. At least one study in adults (van Strien & Bouma, 1990) showed no difference in the ability of males and females to rotate images, but a reduced ability of females to discriminate between a 2D shape and its mirror image when presented to the right hemisphere (left visual field). Another study (Cronin, 1967) found a sex difference in mirror image discrimination in children in kindergarten and first grade, with males outperforming females. If sex differences in mirror image discrimination in infancy are the root of the results of the infant studies of mental rotation described above, then habituating infants to a non-rotating object may elicit similar sex differences in the ability to distinguish between the object and its mirror image, with females failing to distinguish between the images, and males succeeding. This is an important step in elucidating when in development the sex difference in mental rotation arises, and whether it is indeed present already in early infancy, or whether, for instance, the development of a sex difference in mental rotation requires experience with object manipulation. However, if females are unable to discriminate between an object and its mirror image and do not show a preference for the mirror image after familiarization with the object, it is possible that the lack of preference stems simply from not processing or retaining the image of the object at all. To control for this possibility, an additional discrimination between the object and a structural/shape change to the object was added in the current study.

5.1.3 Sex differences in eye expression and face processing in infancy

As reviewed in the previous chapters, sex differences in attention to eyes and faces, and in face processing, and processing of facial features, have been found in many studies, some starting in early infancy. In terms of attention to eyes, for instance, females tend to maintain eye-contact in live interactions, starting from early infancy (e.g. Hittelman & Dickes, 1979; Leeb & Rejskind, 2004). Studies about the different roles the right and left hemisphere play in face processing, starting from infancy, combined with research on sex differences in face processing lateralization, provide evidence that females may be better at detecting a change of features, including perhaps a change of eye expression involving the eye features alone (rather than the location of the eye features). Studies have found evidence to suggest that the right hemisphere specializes in processing configural facial information (i.e. information about the location of the features in the face, the distance between features, etc.) and the left hemisphere is involved in processing featural information, both in infancy (Deruelle & de Schonen, 1998; Scott & Nelson, 2006), and in adulthood (e.g.Hillger & Koenig, 1991; Scott & Nelson, 2006; Maurer et al., 2007). Studies have also found a sex difference in hemispheric lateralization of face processing, with males showing a right hemisphere (left visual field) advantage both in infancy (4-10 months, de Schonen & Mathivet, 1990), and in adulthood (Proverbio et al., 2006; Godard & Fiori, 2010). These studies suggest females may be better than males at recognizing a change in featural information, including eye expression information involving only features, by the age of 4 months. In Chapters 2 and 4, I found that, indeed, 5-month-old females are better than males at discriminating a featural change in eye expression or in the identity of the internal facial features, using the method of habituation to a face, and then testing with sequential test trials of the familiar face and the altered face (with a different eye expression or different features). For face discrimination in general, other studies have found that females are better than males in recognizing familiar (e.g. Barrera & Maurer, 81, 3-month-olds; Bartrip et al., 2001, 1- to 5-month-olds) and familiarized (e.g. Fagan, 72, 5- to 6-month-olds) faces, when these are presented in a single, front-facing position. The current study seeks to replicate the findings of Chapter 2 using a different method (see below), as well as to find possible relations between the ability to discriminate between an object and its mirror image and the ability to discriminate between facial features (in this case, a change in eye expression).

5.1.4 The current study

The current study is divided into two portions – the object portion and the face portion. The main focus of the object portion is to test the abilities of males and females to discriminate between an object and its mirror image, and to see whether infant studies that have found differences in mental rotation between the sexes can be explained in terms of female difficulties in distinguishing between an object and its mirror image. The objects chosen were static images of Shepard-Metzler objects used, rotating, in the studies of Moore and Johnson (2008, 2011), which found sex differences in mental rotation. Similarly to the method used by Quinn and Liben (2008, 2014), side by side shapes were used in both familiarization and test. In the familiarization phase, infants were presented with a maximum of 6 infant controlled habituation trials, in which a Shepard-Metzler object was presented side by side with an identical copy. The habituation criterion was added to minimize attrition due to fussiness of infants who had habituated, and infants were not required to habituate in the familiarization phase in order to be included in the analyses. In the test phase, the infants were presented with two test trials (the mirror image test trials) of the same Shepard-Metzler object presented side by side with its mirror image, with the sides of presentation reversed in the second trial. If infants in either group show a preference for the mirror image stimulus over the familiarized stimulus, it will mean they are able to discriminate between the object and its mirror image. However, if the infants fail to show a preference for either stimulus, it could be simply because they did not encode and/or remember the familiarized objects. To disambiguate these two possible explanations, the two test trials were followed by two additional test trials, the shape test trials, in which the familiarized Shepard-Metzler object was presented alongside the same object with its structure altered (a cube moved). Discrimination of the shape test trials would provide evidence that infants had encoded and retained the shape of the object, and were able to discriminate between the object and another object with a different shape. This in turn would facilitate interpretation of performance on the mirror image test trials.

The face portion is a variation of the method used in Chapter 2. In Chapter 2 infants were habituated, using infant controlled habituation, to a face with a neutral expression but smiling eyes, and then tested with 2 trials of the habituation stimulus, 2 trials with the same face but with the eyes in a neutral expression as well, and 2 trials with a different face. Females, but not males, showed a novelty preference in their first looks to the stimuli, i.e. the ratio between the duration of the first look to the novel (neutral) eye expression test trial and the sum of the durations of the first look to the novel eye expression stimulus and the first look to the familiar (smiling eyes) stimulus was significantly larger than the chance ratio of 50%. In the current study, 3 infant-controlled familiarization trials were used, rather than infant controlled habituation. The familiarization face was the novel eye expression face from Chapter 2, i.e. a face with a neutral expression, though in the current study it was presented smaller, on a different background (black rather than gray), and only from the neck up. Following the familiarization phase, 4 infant controlled side by side test trials were run, as opposed to the sequential test trials in Chapter 2. In the first 2 test trials, the eye expression test trials, the familiarized face was presented side by side with the same face with a novel eye expression (smiling eyes – the familiarized face in Chapter 2), with the sides reversed in the second trial. In the last 2 test trials, the face identity test trials, the familiarized face was presented side by side with a different face, with the sides reversed in the second trial.

For the object portion, it was hypothesized that males would perform the mirror image discrimination better than females, due to deeper ventral processing by the females, uniting the object and its mirror image. For the face portion, it was hypothesized that females would perform the eye expression discrimination better than males, and possibly also the face identity discrimination. Finally it was hypothesized that performance in mirror image discrimination would be negatively correlated with performance in eye expression discrimination.

5.2 Methods

5.2.1 Object portion of study: Stimuli

The object used in creating the stimuli was extracted from a frame from the video used in Moore and Johnson (2008), a video graciously provided by David S. Moore to the authors. Like in the Moore and Johnson (2008) paper, the object was named the L-object and was used to create the novel shape object Ls, and the mirror image of both objects – the R-object and the novel shape object Rs. The L and R objects were 20.8 cm high x 14.8 cm wide, or about 18.2 x 13 degrees of visual angle when viewed from a distance of about 65 cm, while the Ls and Rs objects were 18.8 cm high x 14.8 wide, or about 16.5 x 13 degrees of visual angle. The separation between the centers of the shapes (defined as the middle of the bottom line of the green face of the third cube from the top in the L and R shapes), when the shapes were in the same direction (R R or L L) was 24 cm, or 20.9 degrees of visual angle. When the shapes were in alternate directions the separation between their centers was 26.5 cm, or 23.5 degrees of visual angle (as in L R – note the names of the test trials reflect the presentation of the objects on the screen – the first letter represents the object on the left side of the screen, the second letter represents the object on the right side of the screen) or 21.5 cm, or about 18.8 degrees of visual angle (as in R L).

Object portion stimuli images:

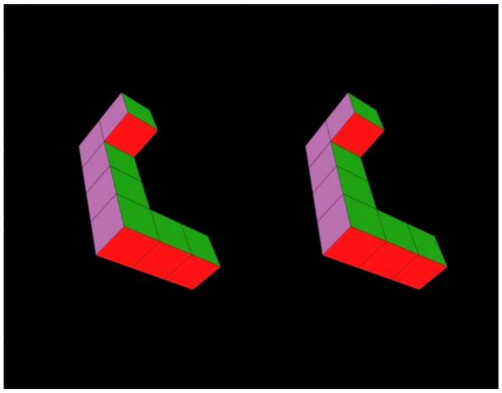

Figure 5.1. Familiarization/habituation stimulus L L – two side by side copies of the L-object. The other habituation stimulus was habituation stimulus R R, in which the R-object (which is the mirror image of the L-object) was presented in the same manner.

Test stimuli:

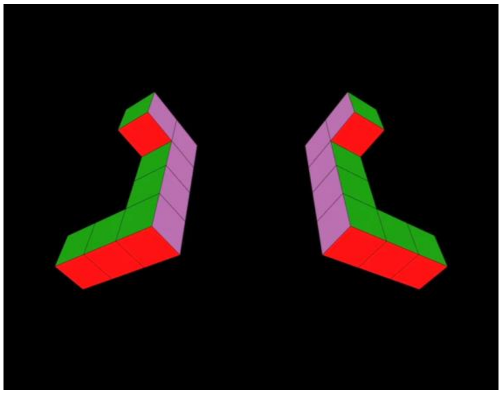

Figure 5.2. A mirror image test trial (R L). The other mirror image test trial is mirror image test trial L R.

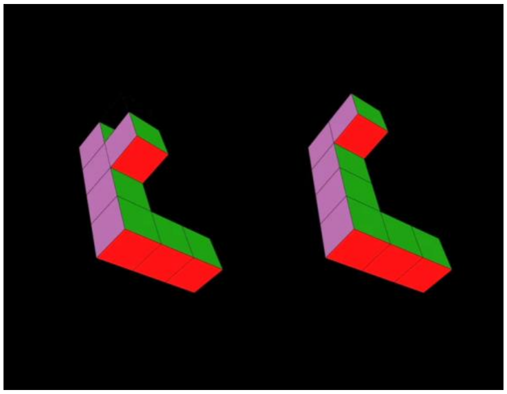

Figure 5.3. A shape test trial (Ls L). The other shape test trial for the L L familiarization/habituation stimulus is L Ls, and the shape test trials for the R R familiarization/habituation stimulus are Rs R and R Rs.

5.2.2 Face portion of study: Stimuli

The stimuli used for familiarization and test were color images of two Caucasian female adult faces. Note the same images were used in Chapters 2 and 3, except for a change in size (smaller in the current study), background (black in the current study, gray in Chapters 2 and 3), the use of the head and neck area without the shirt in the current study, and the side by side presentation of the images in the test trials in the current study, versus presentation of single, centered images in the test trials in Chapters 2 and 3. The familiarization face in Figures 5.4, 5.5 and 5.6 is the face used in the eye expression test trials in Chapters 2 and 3, the smiling eyes face in Figure 5.5 is the face used in the habituation phase and familiar test trials in Chapters 2 and 3, and the novel face in Figure 5.6 is the novel face in Chapters 2 and 3. Three pictures of the two female faces were used to create the stimuli in the study - two pictures of one of the females (female A) – one with a neutral expression (picture A1), and one with a smiling expression (picture A2), and one picture of the other female (female B), with a neutral expression (picture B). As described before, the pictures were taken from the Radboud Faces Database (RaFD), an initiative of the Behavioural Science Institute of the Radboud University Nijmegen (Langner et al., 2010). Adobe Photoshop was used to crop part of the hair of the two females (to increase attention to the internal facial features instead of the hair), to remove noticeable blemishes and scars, to insert the eye expression from the picture of the female with the smiling face (A2) to the picture of the same female with a neutral face (A1), to extract the face and neck from each picture, and to insert the images onto black backgrounds. The faces were approximately 17 cm high and 13 cm wide (hair included), or 14.9 x 11.4 degrees of visual angle when viewed from a distance of 65 cm. When presented side by side, the separation between the centers of the two stimuli was approximately 24 cm, or 20.9 degrees of visual angle.

Face portion stimuli images:

Figure 5.4. Familiarization stimulus – picture of female A with a neutral expression. Hair cropped, background black.

Test stimuli –

Figure 5.5. Eye expression test trial (a) – picture of female A with neutral expression (same as in familiarization), side by side with female A with a neutral expression but smiling eyes. The sides in which the two faces were presented were reversed in Eye expression test trial (b).

Figure 5.6. Face identity test trial (a) - picture of female A with neutral expression (same as in familiarization), side by side with female B with a neutral expression. The sides in which the two faces were presented were reversed in Face identity test trial (b).

5.2.3 Procedure

Each infant was tested in a dimly lit, sound attenuated room. The infant was seated on a parent's lap approximately 65 cm in front of a 32-inch plasma television screen on which the stimuli were presented. To prevent parents from influencing their babies' looking times, the parents' vision was blocked by opaque sunglasses, and they were instructed not to speak or point. A low-light video camera was used to record the infant's face and present it on a computer to an experimenter in another room. The experimenter controlled the study with a computer running the Habit 2002 program (Cohen et al., 2002). The experimenter pressed a button when the infant began fixating the stimulus on the screen, and released the button when the infant stopped fixating the stimulus. The duration of each trial was under the infant's control. Each trial was preceded by 2 seconds of black screen followed by an attention getter which was a static image of a red cross on a black background. Once the infant fixated the red cross, the stimulus of the trial was presented. The trial continued until the infant looked away for 1.5 seconds (or 120 seconds had elapsed).

The first trial was a pretest trial, in which the stimulus presented was a photograph of a field of tulips. After the pretest trial, the object portion of the study began with a familiarization/habituation phase, during which the familiarization stimulus (side by side identical objects) was presented for 6 infant controlled trials or until the infant's looking time decreased to criterion level. To reach criterion, the infant's looking time during 3 consecutive trials had to total 50% or less of the peak looking time – the total looking time in the 3 consecutive trials with the longest total looking time up to that point. A sliding window was used, thus the minimum possible number of trials was 4, and the maximum number was 6.

The subsequent test phase consisted of 4 trials – 2 mirror-image test trials, in which the object used in familiarization was presented side by side with its mirror-image, with the sides of presentation alternating between trials, followed by 2 shape test trials, in which the object used in familiarization was presented side by side with the altered shape version of the object, with the sides of presentation alternating between trials. In the final sample, the males and females were matched in terms of the orders that were run, and the order was counterbalanced in terms of the number of infants habituated to the L-shape and the number of infants habituated to the R-shape, as well as in terms of the number of infants who saw the novel mirror image stimulus in the first mirror image test trial on the right side of the screen vs. the number of infants who saw the novel mirror image stimulus on the left side of the screen. However, in the novel shape trials, in each sex group, 4 infants viewed the novel shape on the right in the first novel shape test trial, vs. 6 infants who viewed the novel shape on the left in the first novel shape test trial. The 10 orders viewed by the 10 infants in each group were as follows (in the order: familiarization stimulus, first mirror image test trial, second mirror image test trial, first shape test trial, second shape test trial, with the letters L, R, Ls, Rs, representing the L-object, R-object, L-object with a changed structure, R-object with a changed structure, respectively, and the trial label X Y representing X on the left side of the screen and Y on the right side of the screen): {L L, L R, R L, Ls L, L Ls} x 2; {L L, R L, L R, L Ls, Ls L}; {L L, R L, L R, Ls L, L Ls} x 2; {R R, R L, L R, Rs R, R Rs}; {R R, L R, R L, R Rs, Rs R}; {R R, R L, L R, R Rs, Rs R} x 2; {R R, L R, R L, Rs R, R Rs}.

The test phase was followed by an object-portion post-test trial, which was identical to the pretest trial.

Following the object portion post-test trial, the face portion of the study began with a familiarization phase, during which the familiarization stimulus (female A with a neutral expression, presented centrally) was presented for 3 infant-controlled trials.

The subsequent test phase consisted of 4 trials – 2 eye expression test trials, in which the familiarized face was presented side by side with the same face with a different eye expression (smiling eyes), with the sides of presentation alternating between trials, followed by 2 face identity test trials, in which the familiarized face was presented side by side with the novel face (female B with a neutral expression), with the sides of presentation alternating between trials. There were 2 orders of presentation – one in which the novel eye expression was presented on the right in the first eye expression test trial and the novel face was presented on the left in the first face identity test trial, and another in which the novel eye expression was presented on the left in the first eye expression test trial and the novel face was presented on the right in the first face identity test trial. Thus, there was a certain level of dependence between the face identity test trials and the eye expression test trials, in that the novel face in the first face identity test trial was always presented on the same side in which the novel eye expression was presented in the previous trial. Each of the 2 orders was presented to half of each sex group (i.e. to 5 males and 5 females).

Following the face portion test phase, the infant and parent returned to the waiting room. An ethnicity questionnaire was administered to the parent by the experimenter, in which the experimenter interviewed the parent about the people with which the infant is familiar, and their ethnicities. Additional questionnaires, including a child characteristics questionnaire, were administered to the parent, and then the infant received a diploma and a small gift for participating.

The videos recorded during the study were later coded offline frame by frame by a trained coder, at a rate of 29.97 frames per second. The first and last object familiarization/habituation trials and all test trials were coded for looking to the left or right stimuli, in between the stimuli, or away, while the remaining object familiarization/habituation trials and the face familiarization trials were coded for infant looks to and away from the stimuli. Measures of looking time were obtained from this offline coding.

As in Chapters 2-4, two social environment variables were extracted from the ethnicity questionnaire – number of people the infant meets (besides his or her parents) at least once a week, for at least an hour (familiar people), and number of adult Caucasian females the infant meets (besides his or her mother) at least once a week, for at least an hour (familiar adult Caucasian females). Regarding motor activity, in the child characteristics questionnaire, parents were asked “What is your child’s current most advanced mode of getting around (no motion, rolling over – to either or both sides, scooting on bum, creeping, crawling, walking, etc.)?” Two motor activity scores were extracted – locomotion (0 – no, 1 – yes), and level of locomotion (0 – no motion, 1 – rolling over, 2 – advancing in any way).

5.3 Study 5 Part 1: Object portion - mirror image and shape discrimination

5.3.1 Participants

Twenty infants were included in the final sample (*M* age = 160.75 days, *SD* = 5.44 days, range 152 to 173 days): 10 females (*M* age = 160.1 days, *SD* = 5.04 days, range 152 to 168 days), 10 males (*M* age = 161.4 days, *SD* = 6 days, range 154 to 173 days). All were first-born, Caucasian, healthy and full term (at least 38 weeks gestation), and living in a two parent home. All but 2 of the infants were hearing English at least 80% of the time – one male was hearing English 40% of the time, and one female was hearing English 75% of the time. Infants were recruited by contact with new parents at the local maternity hospital in Vancouver and by community flyers and referrals. To be included in the final sample, infants had to complete the 2 mirror trials (i.e. look for at least 1 second in each trial) without showing a strong side bias (>80%) in both trials, and look at both of the 2 side by side stimuli in at least one of the 2 mirror image trials and at least one of the 2 shape trials. This criterion was included to ensure the infants had the opportunity to compare the two side by side stimuli. Additional infants were tested but excluded from the analyses for the following reasons: 6 due to crying and/or parent stopping the study (4 females, 2 males), 1 (male) due to not looking for at least 1 second at one of the mirror image test trials , 1 (male) due to failing to look at both of the test stimuli in the shape test trials (i.e. looked at only one of the objects over the two trials), 1 (male) due to a strong side bias in both mirror trials (>85%), 1 due to equipment failure.

5.3.2 Results of Study 5 Part 1: Object portion

5.3.2.1 Familiarization phase

Male and female infants did not differ in number of familiarization trials completed, $t(11.445)=1.396$, $p=.19>0.1$ with equal variances not assumed (*M* males= 5.9, *SD*=0.32; *M* females=5.5, *SD*=0.85). Equal variances were not assumed since Levene's test for equality of variances was significant ($F=11.184$, $p=0.004$). Males and females also did not differ in total looking time during familiarization (analysis was performed on the lg10-transformed total looking times, due to skewness), $t(18)=0.5$, $p=0.62$ (non-transformed parameters: *M* males=50.79, *SD*=16.61, *M* females=50.42, *SD*=35.66). There was a difference in terms of right side bias during the first and final familiarization trials, with females' average preference of the right side significantly greater than chance in each of the trials, while males showed no significant preference in either trial. In the first familiarization trial, for the females, a t-test comparing the right preference to chance (0.5) produced $t(9)=3.16$, p (two-tailed)=0.012, *M* right/(right+left) ratio for females=0.64, *SD*=0.14. In the last familiarization trial, the results were $t(9)=2.452$, p (two-tailed)=0.037, *M* right/(right+left) ratio for females=0.61, *SD*=0.14.

To examine the pattern of looking over trials during the familiarization phase, a 2 (sex) x 2 (trial type: peak, last) mixed-model ANOVA was conducted, with trial type (average looking time on the 3 peak trials, average looking time on the last three familiarization trials) as the repeated measure. The only significant effect was a main effect of trial type, $F(1,18)=12.19$, $p=0.0026$, $\eta^2_p=0.404$ (*M* looking time on peak trials for males=9.49, *SD*=3.56, *M* looking time on last trials for males=7.46, *SD*=4.08. *M* looking time on peak trials for females=11.81, *SD*=10.5, *M* looking time on last trials for females=9.13, *SD*=11.04), consistent with the presence of habituation.

5.3.2.2 Test phase: Mirror image trials

For each of the two mirror image test trials, with the novel mirror image stimulus presented side by side with the familiarized stimulus, a novelty preference ratio was calculated for each individual by dividing the looking time of the infant at the novel mirror-image stimulus by the sum of the infant's looking times at both test stimuli. The two novelty preference ratios were then averaged to produce the infant's mirror-image discrimination score. Infants' mean mirror-image discrimination scores are shown in Figure 5.7.

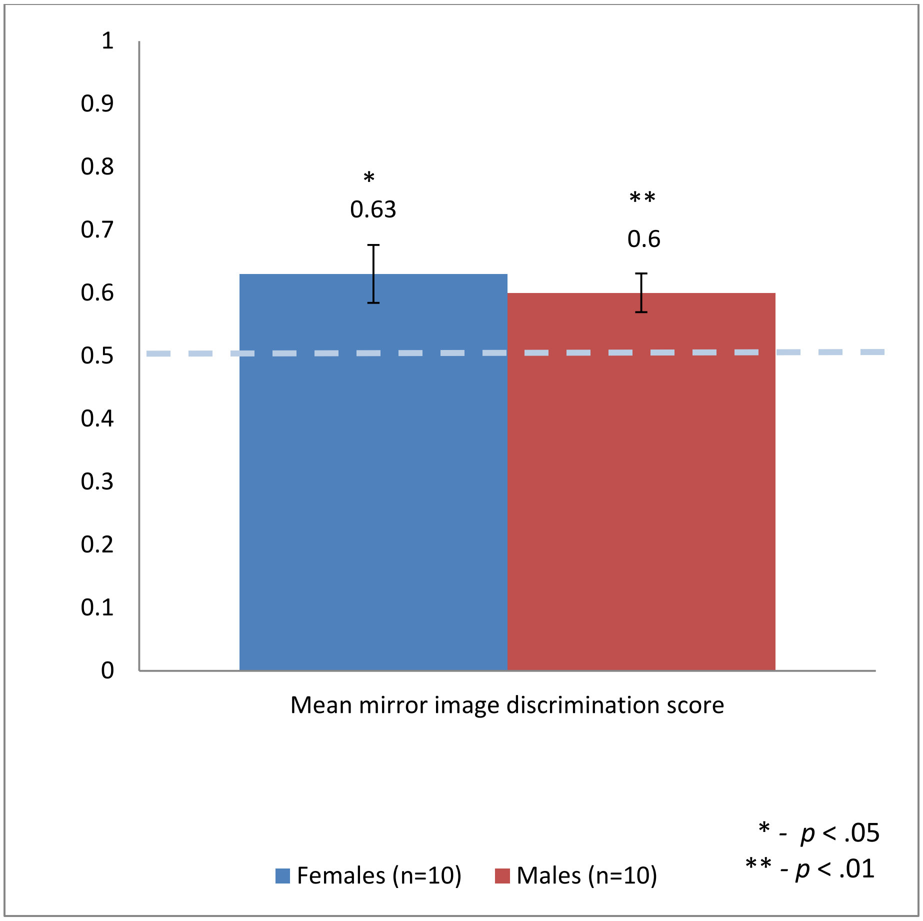

Figure 5.7. Mean mirror-image discrimination scores, by sex

Since discrimination is usually inferred by a novelty preference, i.e. a longer duration of looking to the novel stimulus compared to the familiar stimulus, a one-tailed t-test comparing the mean mirror image discrimination score to chance (0.5) was conducted on each of the two groups. For females, the mean mirror-image discrimination score was M=0.63, SD=.15, $t(9)$=2.79, p=0.011 (one-tailed), effect size (Cohen's d) = .88, thus the females' mean mirror-image discrimination score was significantly greater than the chance score of 0.5. For males, the mean mirror-image discrimination score was M=0.6, SD=.1, $t(9)$=3.15, p=.0059 (one-tailed), effect size (Cohen's d) =1, thus the males' mean mirror-image discrimination score was also significantly greater than the chance score of 0.5. A two-tailed independent samples t-test comparing the discrimination score mean of the males to the discrimination score mean of the females was also conducted, and its results were: $t(18)$=0.56, p=0.58 (two-tailed), that is the female and male means did not differ significantly.

5.3.2.2.1 Effects of side of mirror image stimulus

The effect of the side in which the mirror image was presented in a test trial on the novelty preference in that trial, for each sex, was also examined. In (first or second) mirror image test trials in which the mirror image stimulus was on the right side of the screen, the females' mean novelty preference was significantly greater than chance $t(9)=3.67$, p (one-tailed)=0.0026, effect size (Cohen's d)=1.16 (M female novelty preference with mirror image stimulus on right side=0.72, SD=.19). In mirror image test trials in which the mirror image stimulus was on the left, the females' mean novelty preference was not significantly larger than chance $t(9)=0.59$, p (one-tailed)=0.28, effect size (Cohen's d)=.19 (M female novelty preference with mirror image stimulus on left side=0.53, SD=.18). Thus females showed a significant novelty preference for the mirror image only when the mirror image stimulus was on the right side. For the males, the side on which the mirror image stimulus was presented did not have a significant effect on novelty preference.

5.3.2.3 Test Phase: Novel shape trials

A similar discrimination score was calculated for the novel shape trials, by averaging the novel shape preference over the two novel shape test trials, with the novel shape preference for each trial calculated by dividing the looking time of the infant at the novel shape stimulus by the sum of the infant's looking times at both test stimuli. For one female infant who had only a center look in the first trial, the discrimination score was taken to be the novelty preference in the second trial. Figure 5.8 shows the mean shape discrimination score for the two sex groups. A one-tailed t-test comparing the mean shape discrimination score to chance (0.5) was conducted on each of the two groups. For females, M=.58, SD=.17, $t(9)=1.52$, p (one-tailed)=0.082, effect size (Cohen's d)=0.48. For males, M=.59, SD=.15, $t(9)=1.98$, p (one-tailed)=0.04, effect size (Cohen's d) =0.62. A two-tailed t-test comparing the female mean shape discrimination score to the male mean shape discrimination score did not produce significant results – $t(18)=0.16$, p (two-tailed)=0.87, *ns*. Thus, although the male shape discrimination score was significantly different from chance at a $p<0.05$ level, while the female shape discrimination score was not, the means of the two groups were not significantly different.

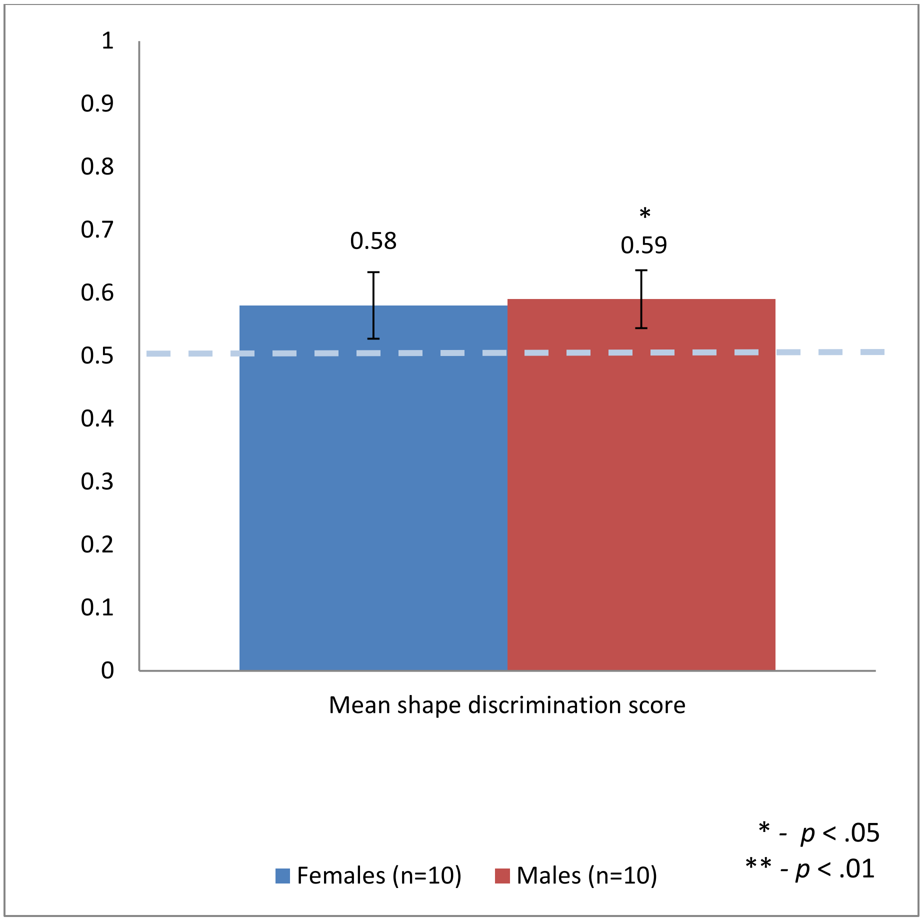

Figure 5.8. Mean shape discrimination scores, by sex

5.3.3 Discussion of Study 5 Part 1: Object portion

In the object portion of the study, it was found that, contrary to my hypothesis, female infants were able to discriminate between the familiarized object and its mirror image, and they did so at a level which was comparable to that of the males. An unexpected finding was a difference between the males and the females in terms of a right side bias. This bias, which appeared in the female group, but not the male group, was found both in the familiarization trials and in the test trials. In the mirror image test trials, females showed a significant novelty preference (i.e. preference for the mirror image, positioned on the right) when the mirror image stimulus was on the right side on the screen, but not when the mirror image stimulus was on the left side of the screen. It is possible that the difference in novelty preference during the test trials between trials in which the mirror image stimulus was on the right side of the screen and trials in which the mirror image stimulus was on the left side of the screen stemmed solely from the tendency of this group to look longer at the right stimulus, evidenced already in the familiarization trials, which was in competition with the tendency to look at the novel stimulus. However, especially since there has been a previous finding in adults (van Strien & Bouma, 1990), of a reduced ability of females to discriminate between a shape and its mirror image when presented to the right hemisphere (left visual field), it is also possible that there is a similar difference in infancy as well, which may influence the ability of the female infants to detect the mirror image when presented on the left side of the screen, leading to reduced discrimination. In terms of shape discrimination, males outperformed females in the sense that the males' novelty preference, as a group, was significant, while the females' was not. However, the difference between the means of the males and the females was not significant, so at least in this sample it cannot be said that the males were significantly better at shape discrimination than the females.

The finding that 5-month-old infants are able to discriminate between an object and its mirror image contrasts with the results of Bornstein et al. (1978) who found no evidence that 3- to 4-month-old infants could discriminate between face profiles and line shapes and their respective mirror images. Sex was not considered in the Bornstein et al. study, and may have been an important factor (e.g. perhaps the lack of discrimination was driven by the females in their study). However, in the current study both sex groups were able to make the discrimination. One possibility for the difference in performance between the two studies is the use of a different paradigm. For instance, Bornstein et al. used sequential presentation of single stimuli, while the current study presented two side by side images. Other possible factors that may have been involved in the difference in results between the two studies are the age difference between the infants in the Bornstein study and the current study (3 to 4 months versus 5 months) and the specific stimuli used (simple line shapes and face profiles vs. a colorful Shepard-Metzler object). Future follow up studies should examine the contribution of these different factors to the conflicting results obtained in the two studies.

5.4 Study 5 Part 2: Face portion - Eye expression and face identity discrimination

5.4.1 Participants

All infants who participated in the object portion of the study went on to participate in the face portion of the study, which was simply 7 additional infant controlled trials (3 familiarization trials and 4 test trials) given to the infants immediately after the post-test slide of the first part of the study. One of the males cried in the post-test and thereafter, and was thus excluded from the analysis of the face portion of the study. Thus, the participants of the face portion were the remaining 19 infants. This also means the male group was not completely counterbalanced with respect to the sides of the presentation of the novel eye-expression stimulus in the first eye expression test trial – 4 were presented with the novel eye expression stimulus on the left, and 5 with the novel eye expression stimulus on the right side in the first eye expression test trial.

5.4.2 Results of Study 5 Part 2: Face portion

5.4.2.1 Familiarization phase

The difference between the mean total looking time during familiarization of males versus females was not significant (analysis was performed on the lg10-transformed total looking times, due to skewness): $t(17)=1.26$, p (two-tailed)=0.261 (non-transformed parameters: M males= 56.96, SD=36.94, M females=42.31, SD=26.95). For the first presentation of the face (i.e. the first familiarization trial), males had significantly longer total looking during the trial compared to females. The difference between the mean total looking time in the first familiarization trial of males and females was significant at the $p<0.01$ level (analysis was performed on the lg10-transformed looking times, due to skewness): $t(17)=2.98$, p(two-tailed)=0.008 (non-transformed parameters: M males= 29.35, SD=20.67, M females=11.83, SD=10.73). For the first look in the first familiarization trial (analysis was performed on the lg10-transformed looking times, due to skewness): $t(17)=1.515$, p(two-tailed)=0.148 (non-transformed parameter for first look in the first face familiarization trial: M males= 16.6, SD=17, M females=10.43, SD=9.24).

5.4.2.2 Test phase: Eye expression trials

As in the case of the mirror image and shape test trials, an eye expression discrimination score was calculated for each infant. For each of the two eye expression test trials with the novel eye expression stimulus presented side by side with the familiarized stimulus, a novelty preference ratio was calculated for each individual by dividing the infant’s total looking time at the novel eye-expression stimulus by the sum of the infant’s total looking times at both test stimuli. The two novelty preference ratios were then averaged to produce the infant’s eye-expression discrimination score. Infants’ mean eye-expression discrimination scores are shown in Figure 5.9.

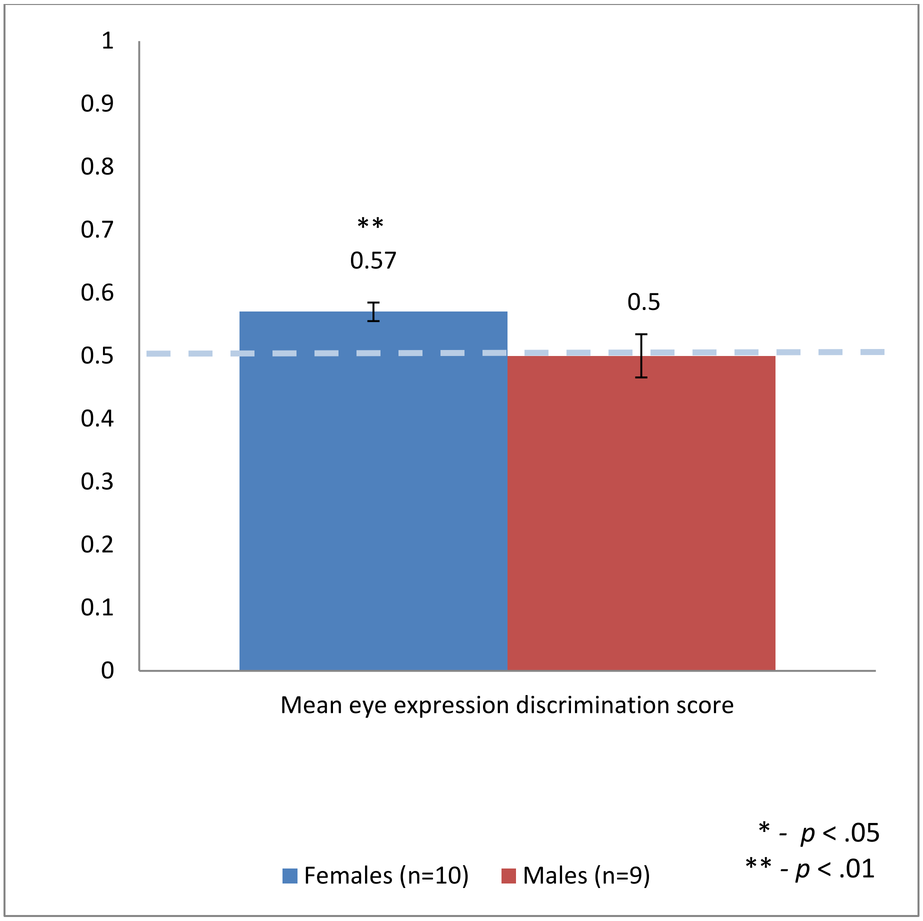

Figure 5.9. Mean eye expression discrimination scores, by sex

To look at the eye expression discrimination of the two sexes, as in the previous sections, a one-tailed t-test comparing the mean eye expression discrimination score to chance (0.5) was conducted on each of the two groups. For females, the mean eye expression discrimination score was M=0.57, SD=.047, t(9)=5, p=0.00037 (one-tailed), effect size (Cohen's d) = 1.58, thus the females' mean eye expression discrimination score was significantly greater than 50%. For males, the mean eye expression discrimination score was M=0.5, SD=0.1, t(8)=0.081, p=0.53 (one-tailed, with the hypothesized direction being that the novelty preference is greater than 0.5), effect size (Cohen's d) = 0.03. A two-tailed independent samples t-test comparing the eye expression discrimination score mean of the males to the discrimination score mean of the females was also conducted, and its results were: t(17)=2.135, p=0.048 (two-tailed), effect size (Cohen's d)=0.98, that is the female mean eye expression discrimination score was significantly greater than the male mean eye expression discrimination score.

5.4.2.2.1 Effects of side of novel eye expression stimulus

The effect of the side in which the face with the novel eye expression was presented in a test trial on the novelty preference in that trial, for each sex, was also examined. On (first or second) eye expression test trials in which the novel eye expression stimulus was on the right side of the screen, female infants showed a novelty preference (i.e. a preference for the right side) significantly greater than chance, with a one-tailed t-test comparing the females' mean novelty preference to 0.5 producing $t(9)=3.51$, p (one-tailed)=0.0033, effect size (Cohen's d)=1.11 (M female novelty preference with novel eye expression on right side=0.63, SD=.12). On (first or second) eye expression test trials in which the novel eye expression stimulus was on the left side of the screen, the female infants' novelty preference (i.e. a preference for the left side) was not significantly greater than chance, with a one-tailed t-test comparing the females' mean novelty preference to 0.5 producing $t(9)=0.244$, p (one-tailed)=0.41, effect size (Cohen's d)=.077 (M female novelty preference with novel eye expression stimulus on left side=0.51, SD=.17). Thus female infants showed a significant preference for the novel eye expression only when the novel eye expression stimulus was on the right side, and showed no significant preference to either side when the novel eye expression stimulus was on the left side. For the males, there was no relation between side of presentation of the eye expression stimulus and novelty preference.

5.4.2.3 Test Phase: Face identity trials

In the face identity test trials, one of the female infants did not look at the two stimuli in either test trial (but looked only to the right stimulus in both test trials). This female was excluded from the analysis of the face identity test trials, leaving 9 males and 9 females. Thus counterbalancing for both sexes was not complete, but matched, with 4 infants of each sex shown the novel face identity on the right side in the first face identity test trial, and 5 infants of each sex shown the novel face identity on the left side in the first face identity test trial. As in the previous sections, a face identity discrimination score was calculated for each infant. For each of the two face identity test trials with the novel face stimulus presented side by side with the familiarized stimulus, a novelty preference ratio was calculated for each individual by dividing the infant's total looking time at the novel face stimulus by the sum of the infant's looking times at both test stimuli. The two novelty preference ratios were then averaged to produce the infant's face identity discrimination score. Infants' mean face identity discrimination scores are shown in Figure 5.10.

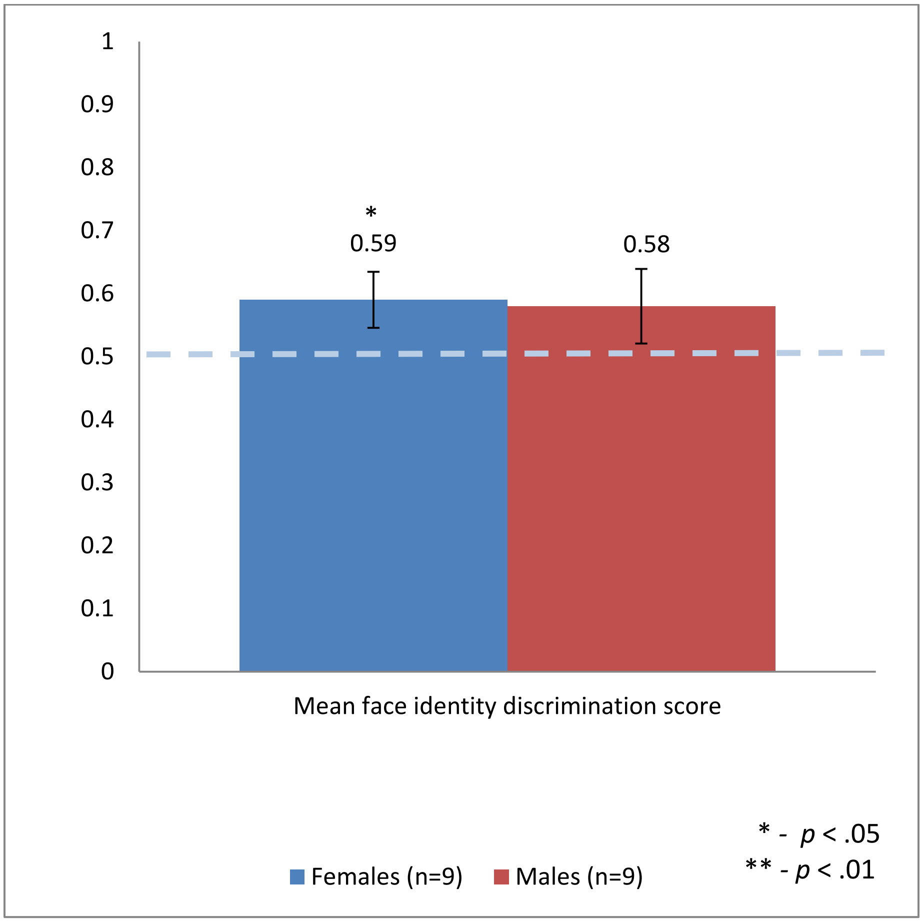

Figure 5.10. Mean face identity discrimination scores, by sex

Once again, to look at the face identity discrimination performance of the two sexes, a one-tailed t-test comparing the mean face identity discrimination score to chance (0.5) was conducted on each of the two groups. For females, the mean face identity discrimination score was M=0.594, SD=0.13, $t(8)$=2.128, p=0.033 (one-tailed), effect size (Cohen's d) = 0.71, thus the females' mean face identity discrimination score was significantly greater than the chance score of 0.5. For males, the mean face identity discrimination score was M=0.582, SD=0.18, $t(8)$=1.387, p (one tailed)=0.101, effect size (Cohen's d) = 0.46. Thus the males' mean face identity discrimination score was not significantly larger than chance. A two-tailed independent samples t-test comparing the face identity discrimination score mean of the males to the discrimination score mean of the females was also conducted, and its results were $t(16)$= 0.164, *p* (two-tailed)=0.87, *ns*. Thus, although the female face identity discrimination score was significantly different from chance, while the male face identity discrimination score was not significantly different from chance, the means of the two groups were not significantly different from each other.

Relation between social environment and locomotion variables and discrimination for the two sexes

The social environment description was not specific enough to extract the social environment variables for two males and one female, so the social environment variables were analyzed for the 7 remaining males (of the 9 who completed the face portion) and 9 remaining females (of the 10 who completed the face portion). With respect to the measures of locomotion and level of locomotion, all infants had the relevant data, i.e. 9 males and 10 females. For locomotion, only one female and one male did not have any form of locomotion, so the locomotion variable was dropped from further analysis. To look at the effects of social environment and locomotion variables on face identity discrimination and eye expression discrimination, the correlations of the 3 variables (familiar people, familiar adult Caucasian females, locomotion level) with the two discrimination scores (face identity discrimination and eye expression discrimination), as well as with each of the novelty scores for each test trial, were calculated, with Spearman's rank order correlation rather than Pearson correlation used in the correlations involving the locomotion level variable since it is an ordinal variable, as in the previous chapters. Because I was interested in these exploratory analyses in asking whether the social environment and locomotion would affect males and females independently, all analyses were conducted for each sex separately.

The results for the males were: For eye expression discrimination, the correlation of the novelty preference in the first eye expression test trial with the number of familiar people was significant at the .05 level: r=.780, p=.039 (r=.781, p=.038 with lg10-transformed number of familiar people, due to skewness) – see Figure 5.11, but the correlations of the second eye expression test trial or the eye expression discrimination score, averaging the two trials, with familiar people were not significant (the correlation of the eye expression discrimination score with number of familiar people was r=.297, p=.517, with lg10-transformed number of familiar people r=.542, p=.209). Although this is an exploratory finding, it suggests that males with a rich social environment are able to discriminate between a neutral and a smiling eye expression presented side by side, at least when the two are initially presented to the infants following familiarization with the neutral eye expression. The same pattern holds for number of familiar adult Caucasian females – the correlation of the novelty preference in the first eye expression test trial with the number of familiar adult Caucasian females was significant at the .05 level: r=.769, p=.043 (see Figure 5.12 in the Appendix), but not the correlations of the second eye expression test trial or the eye expression discrimination score with number of familiar adult Caucasian females (the correlation of the eye expression discrimination score with number of familiar adult Caucasian females was r=.253, p=.584). For locomotion and level of locomotion, none of the correlations were significant (but note the variance of level of locomotion was small – with 7 infants at level 1, 1 at level 0, and 1 at level 2).

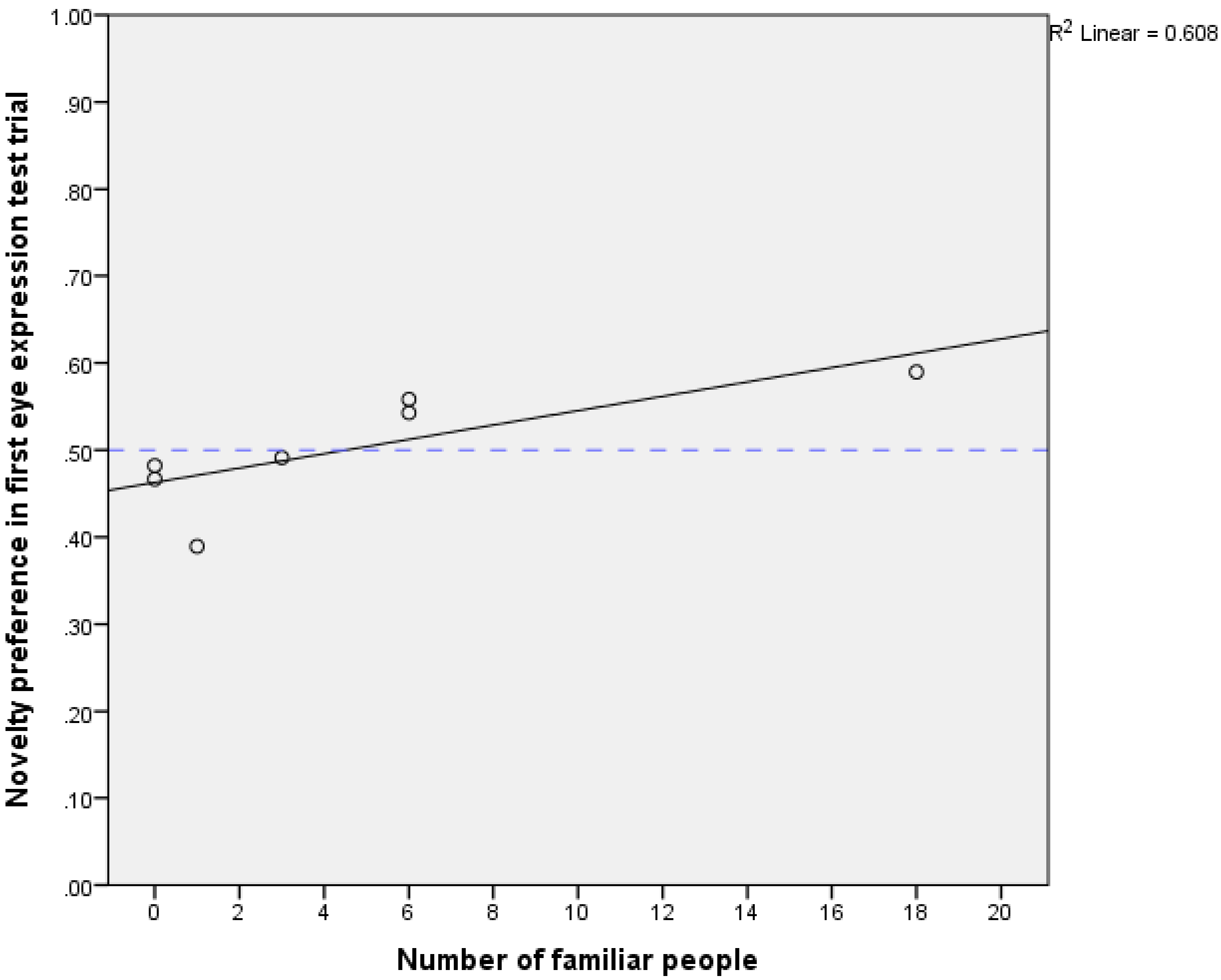

Figure 5.11. Relation between number of familiar people and novelty preference in the first eye expression test trial – males

As for the males' correlations between the social environment and locomotion level variables with face identity discrimination, none of the correlations were significant with the current sample. To sum up, the results of the correlations for the males suggest a relation between the social environment and face discrimination, in terms of eye expression discrimination, with a larger social environment leading to greater novelty preference, in 5-month-old males.

For the females, no significant correlations with either social environment or locomotion variables were found.

Relation between mirror image discrimination and eye expression discrimination

As mentioned in the introduction, one of the goals of this study was to look for a possible relation between the ability to discriminate between an object and its mirror image, thought to be attenuated in infants who tend to use a ventral processing strategy or who have a more developed ventral stream, and the ability to discriminate between eye expressions that differ only in featural information, thought to be enhanced in infants with a more ventral processing strategy or a more developed ventral stream. Thus, for each sex group, correlations were performed between the novelty scores of each mirror image test trial and each eye expression test trial, as well as between the mirror image discrimination score (averaging the novelty scores of the 2 mirror image test trials) and between the eye expression discrimination score. For the 9 males who completed both portions of the study, the correlation between the mirror image discrimination score and eye expression discrimination score was not significant: r= -0.547, p=0.128. The novelty preference score in the first mirror image test trial was significantly negatively correlated with the novelty preference score in the first eye expression trial: r = -0.776, p= 0.014 – see Figure 5.13, and the novelty preference in the first mirror image test trial was also significantly negatively correlated with the novelty preference score in the second eye expression trial: r = -0.728, p= 0.026. For the 10 females, the correlation between the mirror image discrimination score and eye expression discrimination score was not significant: r= -.127, p=0.726, nor were any of the correlations between individual mirror image test trials and individual eye expression test trials (though the tendency in the female group for a relation between novelty preference and side of novel stimulus, may have had a deleterious effect on the individual correlations). Thus, at least for males, there is evidence for the ability to discriminate between an object and its mirror image to be negatively correlated with the ability to detect a change in eye expression.

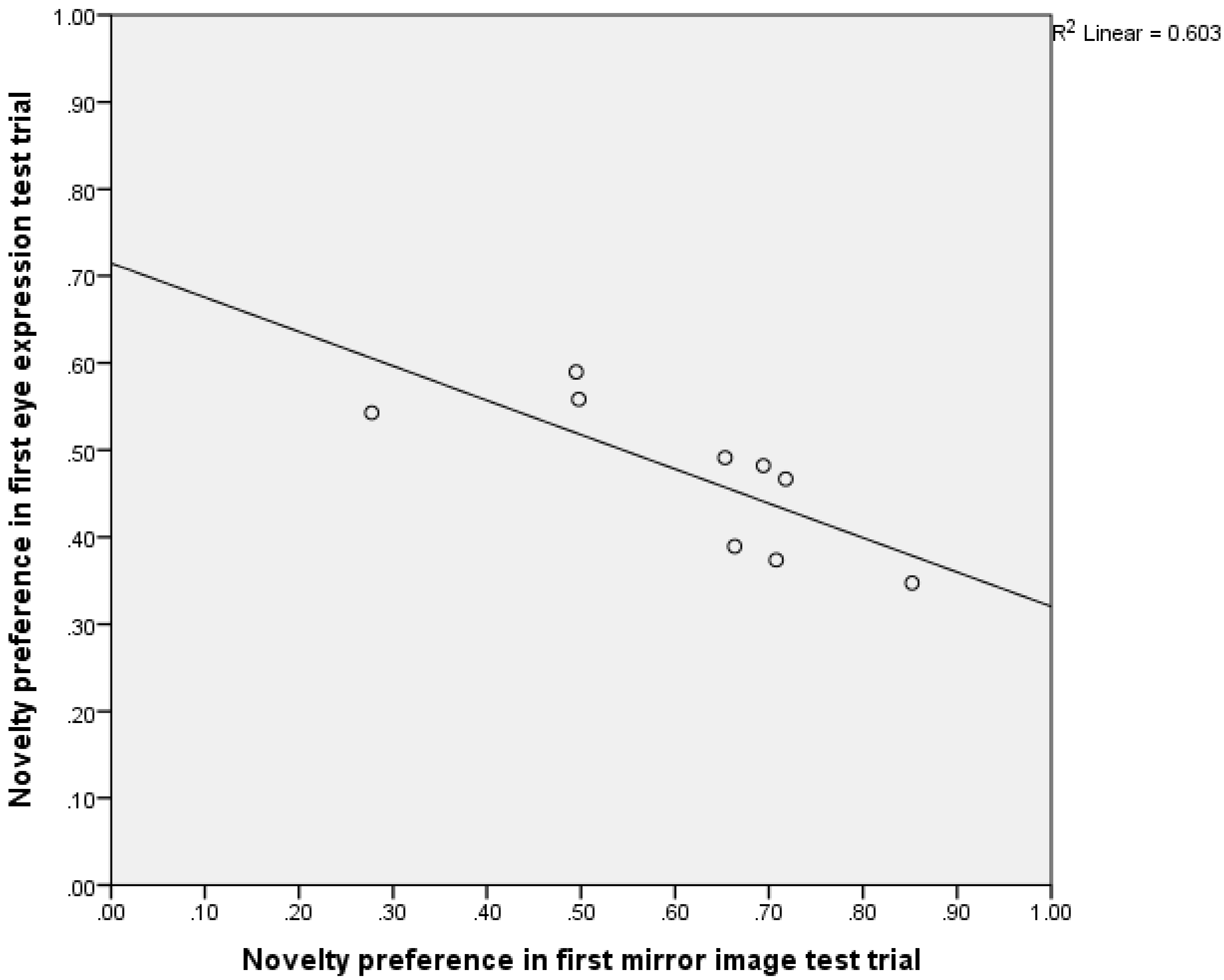

Figure 5.13. Relation between novelty preference in the first mirror image test trial and novelty preference in the first eye expression test trial – males

5.4.3 Discussion of Study 5 Part 2: Face portion, and the relation between the two parts of Study 5

The first important finding in the face portion of Study 5 is a replication of the findings in Chapter 2, that, as a group, 5-month-old female infants are able to detect a change in eye expression, while male infants, as a group, are not able to detect a change in eye expression. This difference holds when the eye expression is changed from smiling to neutral, as in Chapter 2, as well as when the eye expression is changed from neutral to smiling, as in the current study, and it holds whether the test stimuli are presented sequentially, as in Chapter 2, or side by side, as in the current study. In addition, as in the object portion, there was an involvement of side of presentation of the novel eye expression stimulus in the case of the females, but not in the case of the males. Once again, females showed a significant novelty preference only when the novel stimulus was presented on the right.

One possible explanation for the females showing a novelty preference only when the novel eye expression was presented on the right side of the screen is that this bias is related to hemispheric differences in visual processing of faces, with the left hemisphere (right visual field) processing featural information such as the eye expression change in the current study, while the right hemisphere (left visual field) processes configural information, as described in the introduction. Since an emotional eye expression was the expression to be discriminated, it is also possible that the right side advantage of the discrimination was influenced by the specific emotions used. In fact, previous research with adults has found that, when pairs of faces, one neutral and the other showing a faint emotional expression, were shown side-by-side, subjects performed significantly better when the emotional expression was to the right of the neutral face than when the emotional expression was to the left of the neutral face, when the emotional expression was a positive expression such as happiness (Jansari, Tranel, & Adolphs, 2000), with the reverse. i.e. a performance advantage when the emotional expression was to the left of the neutral face, for negative expressions. Furthermore, this valence-specific lateralization effect was found to be significant in females but not in males in several studies (Burton & Levy, 1989; van Strien & van Beek, 2000; Rodway, Wright, & Hardie, 2003). Although only a partial happy expression was used in the current study (i.e. only the eye expression was happy), the right side advantage for females in the current study may be due to a similar effect in infants, with females discriminating the positive emotion better when the emotional face is presented on the right.

In terms of face identity discrimination, the difference between the means of the 2 groups was not significant. This is in contrast to the results of the eye expression discrimination which did significantly differ between the two sex groups, suggesting eye expression processing and/or processing of internal features in general differ more between the sexes at 5 months than the ability to discriminate two completely different faces, with both internal and external, featural and configural differences. This is in line with the results of Chapters 2 and 4.

I also continued the exploratory look at the influence of the social environment and of locomotion on face perception. In the current study I found, once again (as in studies 2 and 4.1), that the social environment of 5-month-old males, in terms of the number of people who are familiar to them, and the number of adult Caucasian females who are familiar to them, affects their performance in tests of face processing. In this case the males' novelty preference in the first eye expression trial was significantly positively correlated with the size of their social environment. This suggests that, for males, eye expression discrimination abilities are enhanced when the social environment is large. In Chapter 2, I did not find evidence for improved eye expression discrimination as a function of a larger social environment in males. However, in that study the presentation of the familiar and novel eye expressions was sequential rather than simultaneous, which may have led to the difference in performance of the males in the two studies, and made the discrimination task easier in the current study (see Caron et al., 1977). This difference in paradigm may also explain why no significant correlation was found in the current study between face identity discrimination and the social environment.

Finally, I looked at the relation between the performance in the mirror image test trials portion and performance in the eye expression test trials. The main finding was that for males, novelty preference in the first mirror image test trial was negatively correlated to the novelty preference in the first eye expression test trial. This is in line with my prediction, and in line with the suggestion that infants with a more advanced ventral stream will be worse at mirror image discrimination and better in eye expression discrimination.

The negative correlation could also be interpreted, however, as interest in objects competing with interest in faces, at least in the case of males. It could be that male infants who were interested in the object task were less interested in the face task, therefore showing less discrimination, and vice versa – whether this reflects their actual interest in objects vs. faces in the real world or not. Interestingly, a recent paper has found a correlation, in 6- to 13- month-old males but not in females, between mental rotation performance (again with Shepard-Metzler objects and a test of mirror image discrimination but using a different paradigm than in the current study), and between preference for a photo of a truck relative to a photo of a doll – the tendency to prefer the truck correlated with better discrimination of the mirror image (Lauer, Udelson, Jeon, & Lourenco, 2015) – which is in line with the suggestion that interest in objects over faces leads to better mirror image discrimination in males, with the opposite preference leading to a decline in mirror image discrimination. However, this pattern is also in line with the suggestion that infants who tend to process through the ventral stream/have a more advanced ventral stream are those infants who tend to prefer face stimuli when these are in competition with other stimuli.

5.5 General Discussion

The current study is part of a series of studies looking at sex differences in visual processing in infancy. In line with the previous studies in the series, I found female superiority in processing featural changes in the face, in this case a change in eye expression. Only females showed a significant novelty preference, and the difference in means between the males and females was significant. This is further support for the hypothesis of a female advantage in the development of the ventral visual stream, and replicates the results of Chapter 2 with a different paradigm, thus strengthening the conclusion that female 5-month-olds outperform males in eye expression discrimination.

With the current paradigm there was some indication that, given a large enough social environment, 5-month-old males are also able to perform the eye expression discrimination. Although replication is required in a larger sample, this result is the first indication in this thesis that 5-month-old males are able to discriminate between eye expressions. The fact that only males with a large near social environment were able to perform this discrimination of a socially relevant signal, suggests that face processing and social developmental trajectories in males are dependent on their near social environment. This finding again points to a need to take individual differences in the size of the social environment into account in studies of the development of face processing and of sex differences in the development of face processing. This finding has implications for studies of populations with atypical face processing and social developmental trajectories, such as infants at high-risk for ASD. Taking the variable of size of near social environment into account in studies of face processing and social development in high-risk infants could elucidate whether this factor has a strong effect on their developmental trajectories as well, and, if so, enriching the social environment of these infants could be found to be a useful early intervention.

In terms of mirror image discrimination, contrary to the hypothesis, with the current paradigm, females were able to discriminate between an object and its mirror image. As mentioned in the introduction, uniting the mirror image with the object occurs in the late stages of the ventral stream (Dilks et al., 2011), and may depend on the ability to identify the object

(Warrington & Davidoff, 2000). Thus, it may be that the females did not process the object fully within the study, or did not process it as an object at all, and therefore did not unite the object with its mirror image. It may be that studies that use a rotating object or different orientations of the object in the familiarization/habituation phase lead to a more complete processing of the object through the ventral stream, and an elimination of the discrimination between the object and its mirror image. Testing the infants with a familiar object, rather than a Shepard-Metzler object, or presenting a moving object at familiarization, but using angles already seen in familiarization as test trials (i.e. not requiring mental rotation in the test trial) may lead to different results in terms of a sex difference in mirror image discrimination. As mentioned in the discussion of the object portion, the absence of mirror image confusion in either sex in the current task stands in contrast to the findings of Bornstein et al. (1978) of mirror image confusion in 3- to 4-month-olds, and follow up studies are needed to clarify the source of these conflicting findings.

In the current study, there were unpredicted effects of side of presentation of the novel stimulus. Females showed a significant novelty preference both in the mirror image and in the eye expression portions only when the novel stimulus was on the right. As described in the discussions of the object portion and the face portion, both of these effects are reported in the adult literature as well (e.g. van Strien & Bouma, 1990; Rodway et al., 2003). Thus, it is possible that a sex difference exists already in infancy with respect to these side preferences, as it does in adulthood. Yet, because a right side bias was also found in the familiarization trials of the object portion, and because there may also be a relation between side bias on the first and second portions of the study, further research is needed to determine whether these sex differences in side preferences are true phenomena in infancy as well.

Finally, in males, but not in females, it was found that performance in the first eye expression test trial was negatively correlated with performance in the mirror image test trials. This is in line with my hypothesis that infants with a more advanced ventral stream will be worse at mirror image discrimination and better in eye expression discrimination, and vice versa. However, in the current study this relation was found only for males, consistent with a similar finding of a male-only relation between preference for looking at a truck over a doll and performance on an object rotation/mirror image discrimination task in another recent study (Lauer et al., 2015), as described in section 5.4.3. It would be revealing to see if further research would replicate these findings. It would be interesting to see, for instance, whether mental rotation tasks, like mirror image discrimination tasks, are also negatively correlated to eye expression or feature discrimination, and whether this holds for both sexes or only for one. Looking at other aspects of the infant's environment and/or intervention studies could show how intertwined these two abilities are, at least in males, and whether different environmental conditions would lead to a different performance in the two tasks, and a different relation between them.

5.6 Conclusion

Visual processing develops differently in males and females. At 5 months, while males have been found to be superior in mental rotation, females are superior in eye expression discrimination. In addition, differences in processing within the two hemispheres, between the two sexes, may also be found already at this young age. However, the environment of the infant seems to exert an effect on these abilities, with males with a large social circle showing eye expression discrimination. Better eye expression discrimination in males was also related to worse mirror image discrimination, and vice versa. This leads to the question of the influence of the environment on visual processing, whether it affects males and females differently, and the possible influence of different interventions on visual processing, as well as on social and cognitive development.

6 Conclusion

This thesis explored sex differences in the development of visual processing in the first year of life. Two ages were tested – 5 months, following a sensitive period for visual processing development, which is also optimal for face processing development in terms of the infants' exposure to faces in the proximal environment and limited locomotion and object manipulation, and 7-8 months, at the end of a period in which many developmental changes in face processing are known to occur, and in which development in other domains such as locomotion has also progressed. Specifically, I asked whether at the age of 5 months, males and females already differ in face processing, in terms of discrimination of a change in features, as well as in object processing, in terms of mirror image discrimination. I also took an exploratory look at two additional factors that may affect the development of face processing – the size of the infant's social environment and the infant's level of locomotion. Finally, I looked at infants at an older age, 7 to 8 months, to see how any differences in face processing develop with time.

A summary of the results is provided below, followed by a more lengthy discussion of the results, their meaning, their implications, and the novelty of my contribution.

The results of the thesis, summarized with respect to the 4 main aims presented in the introduction (Section 1.6) are:

Aim 1. Are there sex and age differences in detection of changes in eye expression?

Yes. In Chapter 2 females showed a novelty preference for a neutral face with a neutral eye expression following habituation to a smiling eye expression at 5 months, and outperformed males, consistent with my hypothesis. This result was replicated in Chapter 5 with a different paradigm, including a different order of eye expressions. In Chapter 3 a developmental shift was found in 7- to 8-month-old females to a familiarity preference, while 7-to-8 month old males did not change their performance compared to 5 month old males, and still showed no significant preference for either eye expression.

Aim 2. Are there sex and age differences in detection of featural changes in the internal facial features (eyes, mouth, nose)?

Yes. In Study 4.1, females were found to outperform males in showing a novelty preference at 5 months, consistent with my hypothesis. By 7 to 8 months, there was no difference in performance between the sexes, and both showed a significant novelty preference. However, it is not clear that at 7-8 months males and females were performing the discrimination in the same way, and this should be explored in follow up studies.

Aim 3. Are there sex differences in mirror image discrimination at 5 months?

Contrary to my hypothesis that males would outperform females, no difference between the sexes was found with the paradigm used, and both showed a significant novelty preference for the mirror image stimulus. There was some indication in Chapter 5 for sex differences in performance related to the two hemispheres, both in mirror image discrimination and in eye expression discrimination.

Aim 4. Is there a relation between mirror image discrimination and eye expression discrimination at 5 months?

My hypothesis that mirror image discrimination would be negatively correlated with eye expression discrimination was supported only for males, and not for females.

6.1 Results and implications

The results of the studies in this thesis indicate that by 5 months, male and female infants already diverge in terms of face processing, with females outperforming males, in line with the hypothesis of faster development of ventral visual processing in females. In Chapter 2 a novel paradigm was used, which tested infants on their ability to detect a featural change in eye expression, following infant controlled habituation. This paradigm enables infants to reveal their sensitivity to a change in eye expression, without any possibility for learning to perform the discrimination during the study itself due to use of a learning task, repeated presentations of the change, or presentation of the two stimuli to be discriminated side by side. To my knowledge, this is the first time infants have been tested on their ability to detect a change in eye expression in a static face. The results showed that only female infants were able to detect a featural change in eye expression from smiling to neutral, as indicated by their first looks, after each infant had had sufficient time to observe and process the face (i.e. following infant controlled habituation). This was not due to males losing interest in the task, since both sex groups were able to detect a complete change in face identity – one that involved a change of both internal and external features, as well as a change in configuration. Although males, as a group, detected the change in face, there was a trend for better performance by the females with respect to face identity, as well as for more variable performance of the males compared to the females, and male face identity discrimination was significantly related to the size of their social environment.

Chapter 5 replicated the results for eye expression with a different paradigm, in which, following familiarization, the face with the familiarized eye expression was presented side-by-side with the face with the novel eye expression in the test trials, rather than presenting the stimuli serially, and in which the order of the familiarization and test stimuli was reversed compared to those used in Chapter 2 (i.e. the change was now from neutral to smiling eyes). Taken together, these results of Chapter 2 and Chapter 5 show that by 5 months, females are already processing the face differently than males, with respect to the eye area. These results are in line with the hypothesis of faster development of ventral visual stream processing in females compared to males.

These results contribute to and inform several fields of inquiry. They contribute to knowledge in the field of face processing, by providing data of specific aspects of face processing in which female development differs from that of males. Specifically, I find differences in detection of featural changes to the eye area, and eye expression. These findings also add to the literature showing enhanced female performance in processing face identity in forward-facing canonical static face images. These results also stress the need to consider the factor of infant sex in all studies of the development of face processing, as well as the need to control other relevant factors, such as ethnicity, in order to allow these differences to be revealed. In terms of the field of sex differences, these results provide evidence that differences in processing of eye area information found in children and adults (e.g., Liu et al., 2013; Kirkland et al., 2013) emerge very early in life, at least by the age of 5 months. Since a change in eye expression carries information that is important for social interaction, these results contribute to the field of social development and sex differences in social development as well.

The detection of the change by the 5-month-old females does not provide information about the meaning of this change to the females or any value attached to the expressions, e.g. whether the smiling eye expression was interpreted as happy, positive, etc. It is even possible that the change was not processed as a change in eye expression, but as a change in eye identity. However, even if it were the case that infants treated the change in eye expression as a change in identity, the pattern of results obtained still reveals data consistent with my hypothesis, that females detect featural changes in the eye area, at an age in which males do not. In addition, no matter how the change is interpreted by the 5-month-old females and what value is assigned to the expressions, the detection of and enhanced attention to the change in eye expression is in itself an important step in the developmental trajectory of the processing of eye expressions.

In Chapter 5 there was also some indication that male infants with a rich social environment may be able to detect the eye expression change in the first trial. Although exploratory, these findings, in combination with the findings of Chapter 2 in which males with a rich social environment were better able to detect a change in face identity than males with a social environment that was not as rich, suggest the difference between males and females is at least in part influenced by the visual input the infants are receiving. The results suggest that an environment rich with familiar faces is required for males to obtain a level of face processing and of eye expression processing that is closer to the level achieved by an average infant female. This may be due to the female infants' stronger inclination to maintain eye contact and to attend to faces in the environment, as described in Chapter 1, which may lead to better learning and development of eye processing and face processing even when encountering unfamiliar people. The exploratory findings also point to a need in the field of the development of face processing and of social development to look beyond the mother-infant dyad and consider individual differences in the social environment of the infants as an important factor in these developmental trajectories as well.

Chapter 3 looked at whether the pattern of sex differences found in Chapter 2 with 5-month-olds was also found in 7- to 8-month-old infants, after many changes had occurred in face processing, facial expression processing, motor abilities, etc. Here a developmental shift was found, from 5-month-old females preferring the novel neutral eye expression stimulus over the smiling eye expression stimulus to which they had been habituated, to 7- to 8-month-old females tending to prefer the familiar smiling eye expression stimulus. For the males, there was still no evidence for detection of the change in eye expression or for any developmental change. The sex difference in detection of a complete change in face identity had disappeared by 7-8 months. However, for males, there was still a trend for a relation between the detection of a change in face identity and the size of the social environment.

The combined results of Chapter 2 and Chapter 3 for eye expression discrimination indicate that during the first year of life, female infants not only look longer at eyes than males in interactions (e.g. Leeb & Rejskind, 2004), they are also becoming eye experts, attending to the eyes in their first looks to a face, and noticing that a change had occurred. While at 5 months their attention may be captured by the change itself, leading to a novelty preference, by 7 months a familiarity preference is found. Several explanations can be offered for understanding the switch from a novelty to a familiarity preference in infants of different ages. In this case, one possible explanation is that this switch is due to the infants' development in terms of understanding the meaning of facial expressions, with eyes with a smiling expression now preferred over eyes with a neutral expression, or in terms of holistic processing of facial expressions, with a half smiling face now considered strange and more interesting or difficult to process. Alternatively, the shift to a familiarity preference may be due to a change of processing strategy from an emphasis on processing the eyes at 5 months to processing the entire facial configuration at 7 months, and only partial processing of the eye features by the time the habituation criterion is reached. This partial processing of the features could lead to a familiarity preference when the eye features are changed, in order to complete the processing of the familiar stimulus.

The results of Chapters 2 and 3 support my hypothesis of a female advantage in eye expression processing, and add to knowledge in the field of face processing development and social development, and of sex differences in these fields. During this period of change in eye expression processing among females, males do not show any sign of detecting a change to the eye area, in a task in which there is otherwise no indication that any change had occurred. The only finding which suggested an ability of males to detect the change was found in males from a rich social environment, in a task where attention is directed to a change occurring (by using one central image in familiarization but two side-by-side images at test), and where the males are able to compare the two stimuli and find the differences between them.

An alternative interpretation of the results of Chapter 5 is that the performance of the males (and possibly also of the females) in Chapter 5 was due to a preference for the smiling eye stimulus when presented side-by-side with a neutral eye stimulus, without relation to the familiarization phase. Sensitivity to subtle degrees of smiling has also been related to visual input, as infants aged 3 months whose mothers encouraged attention to themselves when they were smiling and their infants were looking at them, were more likely to detect and prefer a more subtle degree of a smile when paired with a neutral face (Kuchuk et al., 1986) than other infants. Therefore, the male infants with a rich social environment may have shown a greater tendency to prefer the smiling eye expression when presented side by side with a neutral face, without any encoding and/or retention of the original eye expression in familiarization. Thus, there is no clear indication from either Study 2 or 5, that male infants, even those with a rich environment, attend to the eye expression of a static face presented in isolation, encode the eye expression, and retain it, but only that they can detect a difference in the eye expression of two faces presented side by side, differing only in eye expression. Yet, even if males with a rich social environment are unable to encode and retain the original eye expression, and detect a change to a novel eye expression, the results do suggest that the richness of the social environment enhances their ability to discriminate between eye expressions, albeit in an easier task. Thus, as mentioned above, a rich near social environment seems to enhance male infants' face processing abilities, as well as their ability to discriminate eye expressions. This is an important finding that has implications for the fields of face processing development and social development, and sex differences in these fields.

Future studies could continue to trace the developmental trajectory of detection of a change in eye expression in both sexes, and find if and when in development males evidence detection of a change in eye expression when attention is not directed to a change. The developmental trajectories of the two sexes can then be compared to the developmental trajectories of infants at risk for autism. If the developmental trajectories of infants at risk for autism in performing these tasks are found to be delayed compared to typical males, and if they are found to be related to later autism diagnosis, this simple task could be used for early diagnosis of autism, in addition to enhancing our understanding of the development of autism. Using different experimental paradigms could tease apart the contribution of different factors such as attention to the eye area at encoding and test (e.g. by presenting eyes alone), memory, scanning patterns, etc., to differences in discrimination performance. These results leave key questions open: Would a configural change in the eye area (e.g. raising of the eye brows) be better detected by either sex at either age? What about the role of the particular eye expressions used? And what about changes in facial expressions that are not confined to the eye area?

In Studies 2 and 3, any sign of a sex difference in detection of a change in face identity had disappeared by 7-8 months. However, the change in face identity in the studies in Chapters 2 and 3 included changes both to the external and internal features, as well as to the relations between the features. Thus, it was possible that the same discrimination was performed using different information by the males and females who performed the discrimination. This was explored in Chapter 4.

Chapter 4 looked at the development of discrimination of the internal facial features. Again, novelty preference ratio in the first looks was the dependent variable, and the method used served to reveal the infants' sensitivity to such changes without any learning within the experimental setting. As predicted, 5-month-old females outperformed 5-month-old males in the ability to detect a change in internal features (eyes, nose, and mouth), with minimal configural changes. This is further indication of a female advantage, at 5 months, in detection of featural changes in a face, and presumably of faster development of ventral visual processing in females, and adds to the knowledge in the fields of face processing and visual processing development and of sex differences.

Though all features were changed, compared to only a change in the eye area in the study in Chapter 2, this did not lead to enhanced discrimination performance by the females. Therefore, it is possible that at 5 months, females based their discrimination of the two faces with different features, only on the change to the eye area. Thus, follow up studies should look at sex differences at 5 months in the ability to detect a change of identity based on a change in a single feature (e.g. eye identity) alone, with or without the involvement of a change in expression. By 7-8 months, infants of both sexes were able to discriminate faces on the basis of internal features, with no significant difference between the sexes.

While both males and females performed equivalently at 7-8 months, it remains unknown whether the 7- to 8-month-old males and females performed the discrimination in the same way. It is possible, for instance, that males performed the discrimination only using holistic/configural processing (a type of processing which undergoes major developmental changes between 5 and 7 months), while the females attended to the change to individual features as well. Hillger and Koenig (1991), for instance, found that, in adults, changes to all 3 features (nose, mouth, eyes) were processed differently than changes to a single features, with a right hemisphere advantage for all 3 features, vs. a left hemisphere advantage for a single feature. A similar difference could hold for male vs. female infants as well, with males processing the difference only using their right hemisphere, while females are able to use both hemispheres. Thus, the possibility remains that females at 7-8 months are able to detect a change to a single feature, e.g. a change in the identity of the eyes alone, better than males, as they did in the case of eye expression. Therefore, this result in 7-8 months is a starting point to further exploration of the differences in the developmental trajectories of face processing in males and females.

The study in Chapter 4, like the previous studies mentioned, found some evidence (though marginal, with p's between 0.05 and 0.1) of a relation between the social environment of males and face processing, in this case the whole face discrimination. The combined results of the different studies suggest that, at least for males, the size of the social environment is related to face processing. For females, throughout the set of studies, locomotion was related to measures of discrimination, with a lower level of locomotion associated with more developed processing. It is possible that the interaction between the two variables, as well as their distributions within the specific samples, obscured similar relations between size of social environment and face processing for females, and between locomotion and face processing for males. However, in terms of the relation to the size of the social environment, a recent study with adults (Sommer, Hildebrandt, Kunina-Habenicht, Schacht, & Wilhelm, 2013) found similar results, with males' activities (things vs. people oriented) related to their face memory, with more "things-oriented" activities significantly negatively correlated with face memory, while more "people-oriented" activities tended towards significance for being positively correlated with face memory. For females, things-oriented activities positively correlated with face memory, while people-oriented activities were not associated with face memory. Thus, it is possible that the size of the social environment affects males and females differently, and has a stronger effect on the face processing and attentional development of males. Future studies, with larger samples, should explore these relations further.

Differential influences on males vs. females from the social environment may also have implications for the development of autism. According to the "extreme male hypothesis" (see Baron-Cohen, 2002), in individuals with autism there is an exaggeration of the sex differences found in typically developing populations, with the individuals with autism being even farther from typically developing females than typically developing males, e.g. in terms of social skills, including aspects such as processing of eye expressions and other aspects of face processing. My findings showing an influence of the social environment on the development of face processing and eye expression processing thus have important implications for the study of autism. The results point to a need to study the relation between face processing development and the size of the social environment, and, in general, between social development and the size of the social environment, in infants at high risk for autism. Enriching the social environment of infants at risk for autism may even be found to be a useful intervention to lower the risks of developing autism. Understanding the influence of locomotion development and motor activity in general on the development of face processing, in both sexes, may also have important implications, both in terms of understanding human development, and in relation to the development of autism, in which atypical motor development trajectories are also common and have been related to autism symptoms (e.g. Bhat, Galloway, & Landa, 2012). In general, the exploratory look at the social environment and locomotion variables in the current set of studies, which produced promising results, points to a need for incorporating these variables in future studies of the development of face processing.

Chapter 5 looked at sex differences at the age of 5 months in mirror image discrimination and in the processing of eye expression, and at the relation between the two abilities. In this chapter a different method was used, in which the familiar and novel stimuli were presented side-by-side at test. This method enables the infants to compare the two stimuli directly and is thus less revealing in terms of the sensitivity with which the infants came into the study, but adds information that presentation of a single central stimulus cannot provide, like information about laterality effects. This method may also make discrimination easier (Caron et al., 1977) and thus may reveal an ability to perform the discrimination in groups which fail the harder, sequential task, furthering knowledge of infants' abilities. In the mirror image portion of the study, it was hypothesized that males would outperform females in mirror image discrimination. Contrary to my hypothesis, no overall sex difference in performance in mirror image discrimination was found. This does not rule out the involvement of mirror image confusion in the previously published results obtained in mental rotation studies with infants, as, for example, it is possible that presenting the image from only one angle does not result in mirror image confusion, but the presentation of the image from various viewpoints is required. Future studies should investigate this issue by, for example, presenting the image in different rotations and using one of the rotational angles presented in familiarization in the discrimination test. The results of the study, in which neither sex showed mirror image confusion, also stand in contrast to the findings of Bornstein et al. (1978) which showed mirror image confusion is already found in 3- to 4-month-old infants. Future studies are also needed to elucidate the source of this difference between the two studies, and whether it stems from the use of different stimuli, a different paradigm, a different age group, or etc. Thus, this negative finding with respect to mirror image confusion points to a need for further research in the field of visual processing development, to determine the factors that are necessary to produce mirror image confusion in infancy.

Although no overall sex difference in mirror image discrimination was found, a difference was found in terms of side biases. Females, unlike males, showed a significant novelty preference for the mirror image only when the mirror image was presented on the right. Because females also showed a right side bias in the familiarization trials, it is unclear whether the novelty preference for the mirror image only on the right stems solely from this right side bias, or whether other causes, such as differences between the two hemispheres in visual processing, are involved. Since at least one adult study found similar results in adults (van Strien & Bouma, 1990) with a reduced ability of females to discriminate between a 2D shape and its mirror image when presented to the right hemisphere (left visual field), this result merits further exploration in additional studies with other stimuli, perhaps stimuli similar to those used in the van Strien and Bouma (1990) study. Such further investigation would help determine whether this sex difference is present already in infancy.

In the eye expression discrimination part of Chapter 5, as mentioned above, the results replicated those of Chapter 2, using a different paradigm – only females showed a novelty preference for the novel smiling eye expression over the familiar eye expression, and the means of the two sexes were significantly different. In this study, the male face identity discrimination scores were not correlated with the size of the social environment of the males, unlike in the case of sequential presentation of test stimuli used in Chapter 2. The presentation of side-by-side stimuli may have made the task easier (see Caron et al., 1977), thus eliminating the effect of the social environment. This difference in paradigm may also have caused the performance of the males and the females in the face identity trials to be more similar, with the means between the groups showing no sign of a difference.

As in the object portion of the study, side biases in females, but not in males, were found in the face portion of the study. Females, as a group, showed a novelty preference for the novel eye expression only when the novel stimulus was presented on the right side of the screen. Once again, while this may be a result of the tendency in this specific group of females for a right side bias, this result could also be meaningful. The side bias could be related to hemispheric differences in visual processing of faces, with the left hemisphere (right visual field) processing featural information such as the eye expression change in the current study, while the right hemisphere (left visual field) processes configural information. The side bias could also be related to the valence-specific lateralization effect, in which a positive expression is detected better when presented to the right of a neutral expression (Jansari et al., 2000), with the reverse pattern for negative expressions. As mentioned in Chapter 5, several studies have found this lateralization effect to be significant in females but not in males (Burton & Levy, 1989; van Strien & van Beek, 2000; Rodway at al., 2003). Thus, the results of the current study suggest studying sex differences in the valence specific lateralization effect in infancy may prove a fruitful line of research.

As for my hypothesis that mirror image discrimination would be negatively correlated with eye discrimination, this was found only in males. This result is in line with the idea that a more developed ventral stream or a tendency to process with the ventral stream would result in both an inability to discriminate the mirror image and an ability to detect fine changes in the face. The result is also in line with the suggestion of differential performance as a function of interest – with infants interested in objects more than faces performing relatively well in object discrimination but relatively poorly in face discrimination, and vice versa. Importantly, these two interpretations are not mutually exclusive, as differential interests may drive and/or be driven by different visual processing abilities. In either case, this finding, of a male, but not a female, interest in objects vs. faces being positively related to mirror image discrimination and negatively related to face processing, has parallels in both the older infant and adult literature. Lauer et al. (2015) found that in 6- to 13-month-olds, mental rotation performance (in yet another paradigm in which evidencing mental rotation relies on mirror image discrimination) was correlated with greater visual interest in a toy truck over a doll in males, but not in females. In adults, as mentioned earlier (Sommer et al., 2013), face memory was related to less "things-oriented" activities and more people-oriented activities, in males but not in females. If, indeed, in infant males, expertise with faces is negatively related to expertise with objects, this information would need to be taken into account when planning intervention studies to improve face processing in at-risk populations.

6.2 Limitations

Whenever designing an experiment, a number of decisions have to be made. Because of the hypotheses guiding my studies, I chose to apply very strict criteria for inclusion in the sample rather than include a very broad sample of infants who differed in these characteristics. Thus infants were required to be first-borns, with a mother who has a Caucasian (ethnically European) appearance, and in the study of facial features (Study 4) – also from English-only speaking families. This severely limited the number of subjects we could recruit leading to small sample sizes, but also eliminating some of the sources of noise that could have made it difficult to test my hypotheses. Although the sample sizes chosen for the studies were small, they were within the range used in previous studies probing for and finding sex differences in perceptual processing in these age groups (e.g. Pascalis et al., 1998; Barrera & Maurer, 1981; Wilcox, Alexander, Wheeler, & Norvell, 2012; Quinn & Liben, 2012). One attempt to overcome the small sample sizes was by replicating the study in Chapter 2 in the second part of Chapter 5. The replication, using a different paradigm, and a different order of familiar and novel stimuli, produced similar results, thus strengthening the conclusions of Chapter 2. Although with the sample sizes used in my studies I did find results that were significant or bordering on significance, increasing the sample size and thus increasing statistical power may have resulted in additional significant findings.

As in any infant study, concerns regarding representativeness of the sample are present in the studies in this thesis as well. One of the sources for concern stems from the proportion of families agreeing to participate in a study once contacted (around 10%). It is possible that there is a self-selection bias based on temperament that favors infants whose parents believe they are more likely to sit still for the duration of the study, e.g. infants with a lower activity level. Since infant males have been found to be more active than infant females (e.g. Eaton & Enns, 1986), this bias could have resulted in a sample of infant males that is less representative of the infant male population in terms of activity level than the sample of infant females is representative of the infant female population. However, the findings in my studies suggest that a lower activity level (represented in this thesis by measures of locomotion development) leads to better face processing, in line with the Libertus and Needham (2014) finding of a greater preference for looking at faces over objects in infants who are less motorically active. Therefore, if such a self-selection bias had an effect on the results, it would more likely work against rather than favor my hypotheses, and thus the sex difference in the population may be even greater than the difference found in my studies.

Another limitation of the studies is that one set of face stimuli was used throughout the study, and other than in the replication of Study 2 in Study 5, also a single order of which stimulus was used as familiar and which stimulus was used as novel. This was again due to the difficulty in recruiting subjects, as using different stimuli would require a greater number of participants to ensure there was no effect of the particular stimuli on either sex group. However, the results require replication to ensure they are not specific to the stimuli used in the study. The use of one order of stimuli also means a priori preferences in either group of infants for one type of stimulus over the other may have influenced the results. Thus, while results in which a group of infants favors one stimulus over the other clearly indicate an ability to discriminate between the stimuli and to attend to information relevant to the discrimination, it cannot be concluded from a novelty preference, for instance, that the original stimulus was encoded and the novel stimulus was preferred solely due to its novelty. An example of the drawbacks of using one set of stimuli is found in Chapter 3, as it is unclear whether the familiarity preference found in the female group is a result of the order of facial expressions used in the study, and follow up studies are needed to clarify this issue.

The sample sizes used also enabled looking at only a small number of factors which may influence the development of face processing. A few factors were used as selection criteria for the sample (such as ethnicity), and four factors related to social environment and locomotion were used for exploratory analysis of their influence on face processing. However, many additional factors that may have an effect on the development of visual processing and visual attention were not considered. It is possible that the differences found in the samples are influenced by one or more of these factors. For instance, maternal depression has been found to be related to facial expression discrimination at age 5 months (Bornstein et al., 2011), and data on maternal depressive status were not collected in my study. Maternal depression may also be confounded with the size of the social environment of the infant, both in my study and in studies like Bornstein et al. (2011). Therefore, future studies looking at the relation between the social environment and face processing abilities should also consider maternal depressive status, and vice versa. The concern for several other third factors having a major contribution to the results found can be partially assuaged by the consistent pattern of results within three different samples of 5-month-olds. In all three independently drawn samples, the same main finding, of a female advantage over males in the detection of a change in one (eye expression) or all internal features, was found.

Finally, as elaborated upon in section 2.4, the variables chosen to represent the richness of the social environment as well as motor activity were limited in scope, and future studies looking at the relation between social environment/motor activity and the development of visual processing and face processing should consider additional factors such as the amount of contact with the familiar people and the time spent observing their faces, the type and duration of interaction between the familiar people and the infant, the trajectory of locomotion development, etc. Intervention studies in which the number of familiar faces in the infant’s repertoire is increased could address the issue of the factor of number of familiar people being confounded with the size of the parents’ social circle, and thus, e.g., with genetic influences on the infant’s social tendencies and face processing abilities.

6.3 Future directions

The results of the studies in this thesis support the conclusion of a sex difference in face processing by the age of 5 months. As described in Section 6.1, these results open the door to additional studies clarifying the nature of these sex differences. Priority questions that stem from these results are: Are the differences in expression processing specific to eye expressions or might they include processing of facial expressions in general? Are the sex differences specific to featural changes or are there sex differences in the development of configural processing as well? Are 7- to 8-month-old male and female infants, who can detect a change of all three internal features, performing the discrimination using the same strategy? The results of the exploratory look at the factors of social environment and locomotion inform the field of face processing as well as the field of sex differences in development about additional variables that need to be considered when looking at differences in the development of face processing and attention to faces – namely the size of the social environment as well as motor aspects of development such as locomotion.

While finding such early differences, presumably in the development of the ventral visual stream, and specifically in the development of the processing of eye expression and internal facial features is an important and novel contribution to the literature, the question of the source of these developmental differences still remains unanswered. One possibility raised in the thesis, and supported by the exploratory findings with respect to the size of the social environment, is that the sex difference in the development of face processing and perhaps of additional aspects of the ventral visual stream is related to differences in the amount and variability of exposure of the infant to eyes and faces. Combining the paradigms used in our studies with head mounted eye-tracking of the same infants outside the experimental setting would enable to explore the relation between the infant's actual experience with faces and eyes and their face processing development. In addition, eye tracking studies within the experimental setting could also provide valuable information, both by using eye tracking within the same paradigm and looking at the relation between individual scanning patterns and performance in such discriminations, and by relating scanning patterns of dynamic faces (e.g. an adult speaking) to individual performance in such discriminations.

Sex differences in the development of face processing within each of the two hemispheres also seem to be a promising area for future research. Scott and Nelson (2006) found that 8-month-olds, but not 4-month-olds, detected a change in eye and mouth features to those of another female's face, as well as in configuration (distance between the eyes and distance between the nose and mouth), and using ERP also found that at 8 months and in adulthood, there are hemispheric differences between configural and featural processing, with, e.g., a larger left hemisphere than right hemisphere response to featural changes. Scott and Nelson (2006) did not attempt to look for sex differences. My findings of detection of featural changes by females, but not by males, at 5 months, suggests using stimuli such as those used in Chapter 2 may reveal patterns of ERP results similar to those of 8-month-old infants in 5-month-old females, but not males. Using the ERP method on 7- to 8-month-olds with all three features replaced may also elucidate whether the male and female infants process the change in the same manner, or whether, for instance, males use the right hemisphere more than females to perform the same task. The results of this thesis also point to the need to take sex into account in all studies of the development of face processing.

6.4 Concluding statement

Sex differences in attention to faces, in face processing and in processing of facial expressions are a common finding. In this thesis, I have shown that the development of these skills, part of the ventral visual processing stream, in males and females has already begun to diverge by the age of 5 months, and that this development may depend on additional factors such as the size of the infant's social environment and the motor development of the infant. These findings advance knowledge in the fields of the development of visual processing and of face processing, as well as the fields of social development and sex differences in important ways, and serve as a starting point from which to explore further the development of the crucially important skill of face processing in humans, as well as what goes awry with this development in conditions like autism. According to the "extreme male hypothesis" (see Baron-Cohen, 2002), in individuals with autism there is an exaggeration of the sex differences found in typically developing populations. Thus tracing the development of these sex differences and looking for their underlying causes could help understand the development of autism as well. Finding factors which positively influence face processing development at these young ages may even lead in the future to development of early intervention programs for infants at risk for autism. This is in addition to informing the scientific community and the general public about the influence of the infant's environment on his or her development, and about the relation between the infant's developmental trajectories in different domains.

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Appendix

A1: Chapter 2 Additional Figures:

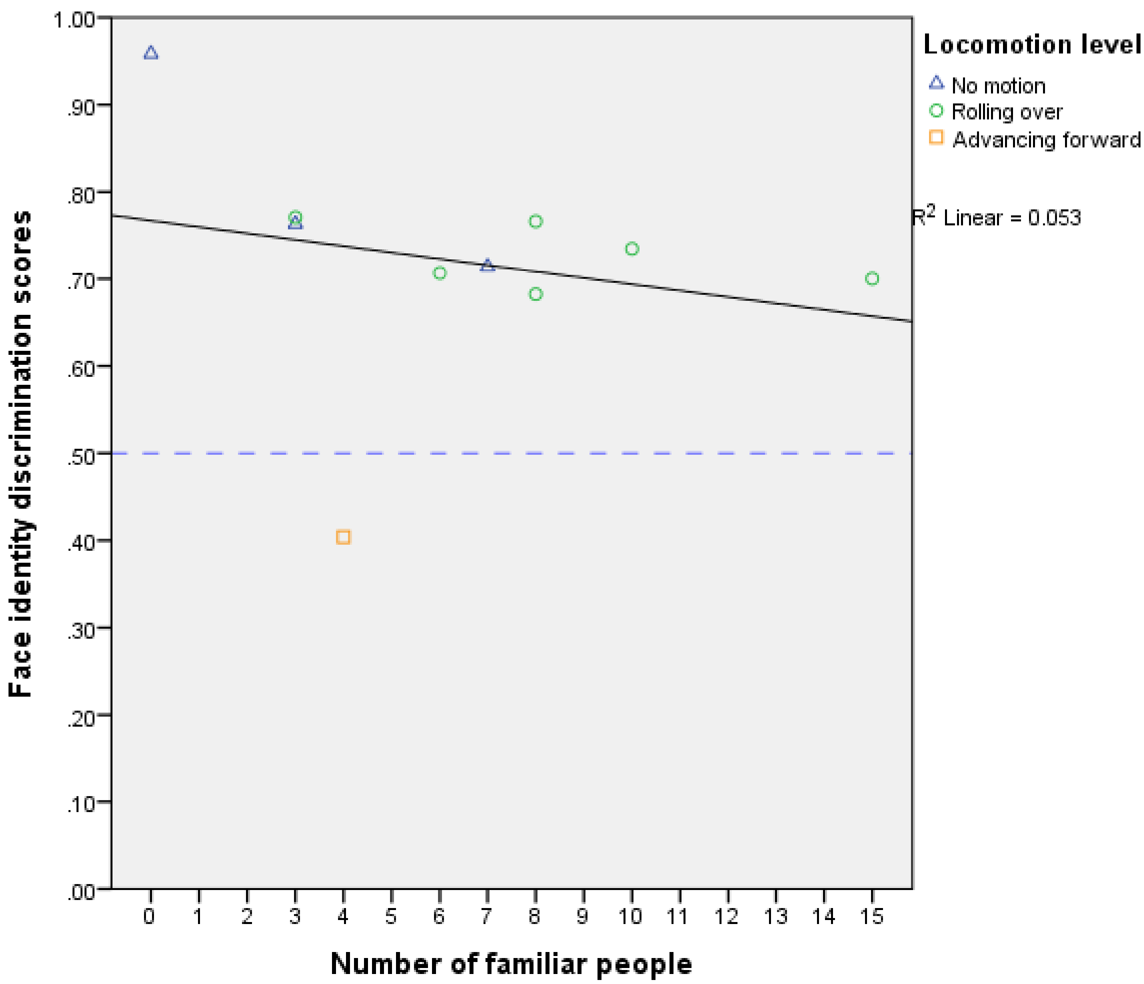

Figure 2.11. Relation between number of familiar people and face identity discrimination, with locomotion level marked – 5-month-old females

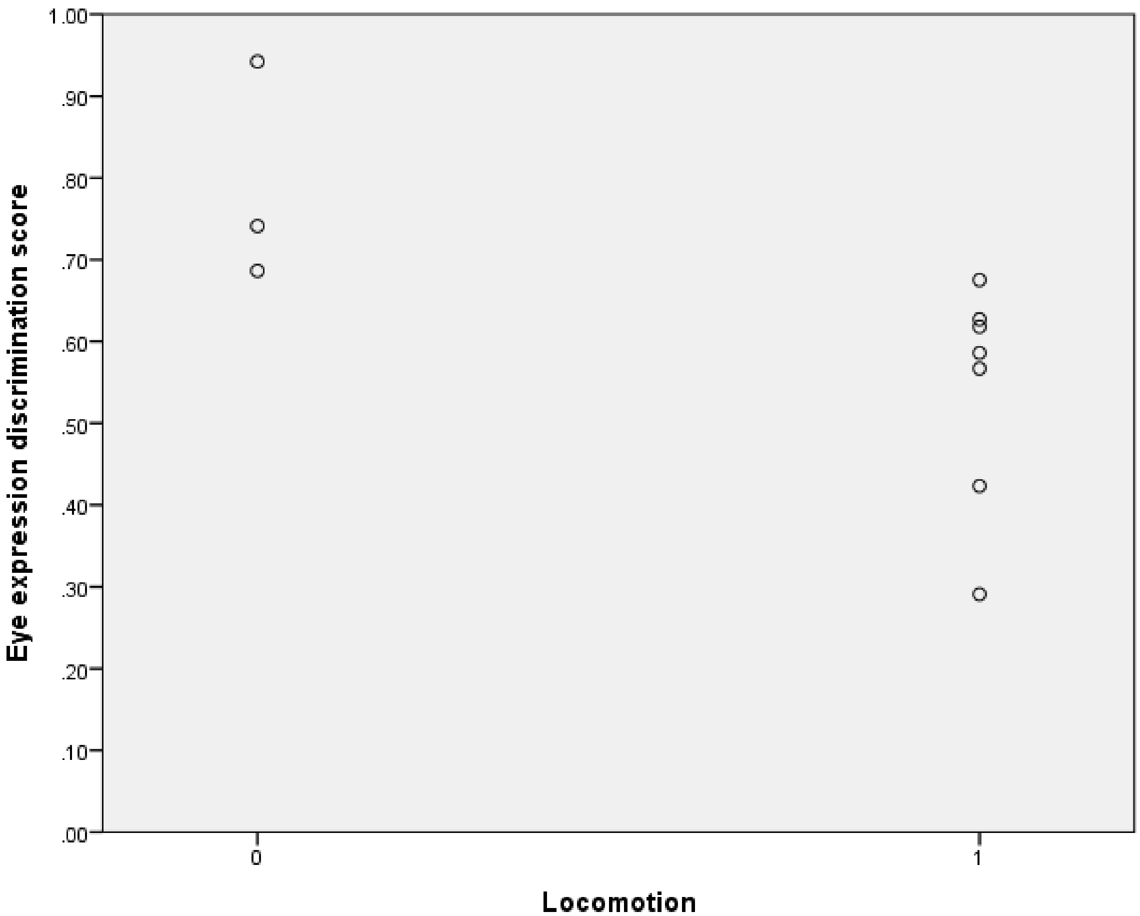

Figure 2.13. Relation between locomotion (0 – no locomotion; 1 – rolling over or more) and eye expression discrimination – 5-month-old females

A2: Chapter 4 Additional Figures:

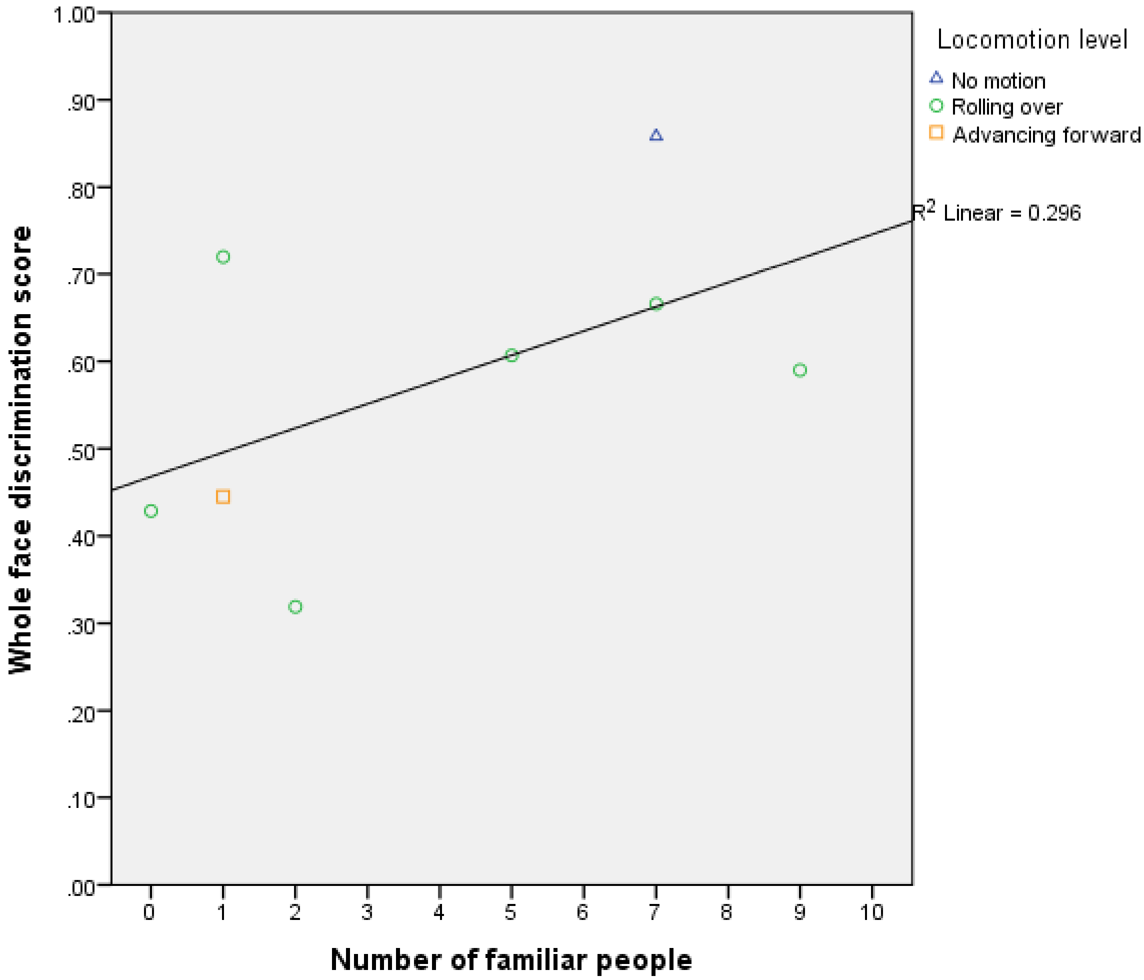

Figure 4.10. Relation between number of familiar people and whole face discrimination, with locomotion level marked – 5-month-old females

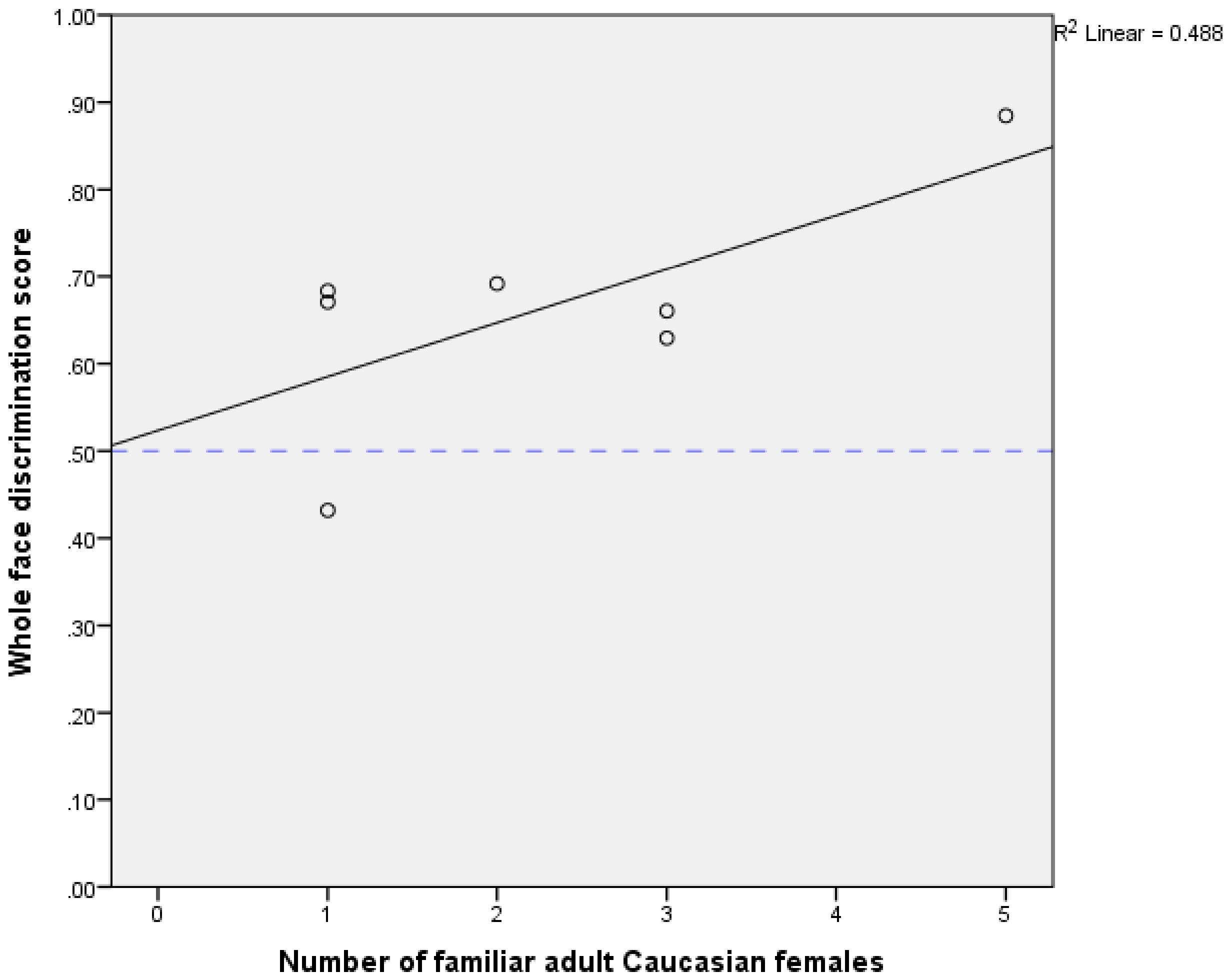

Figure 4.15. Relation between number of familiar adult Caucasian females and whole face discrimination – 7- to 8-month-old males

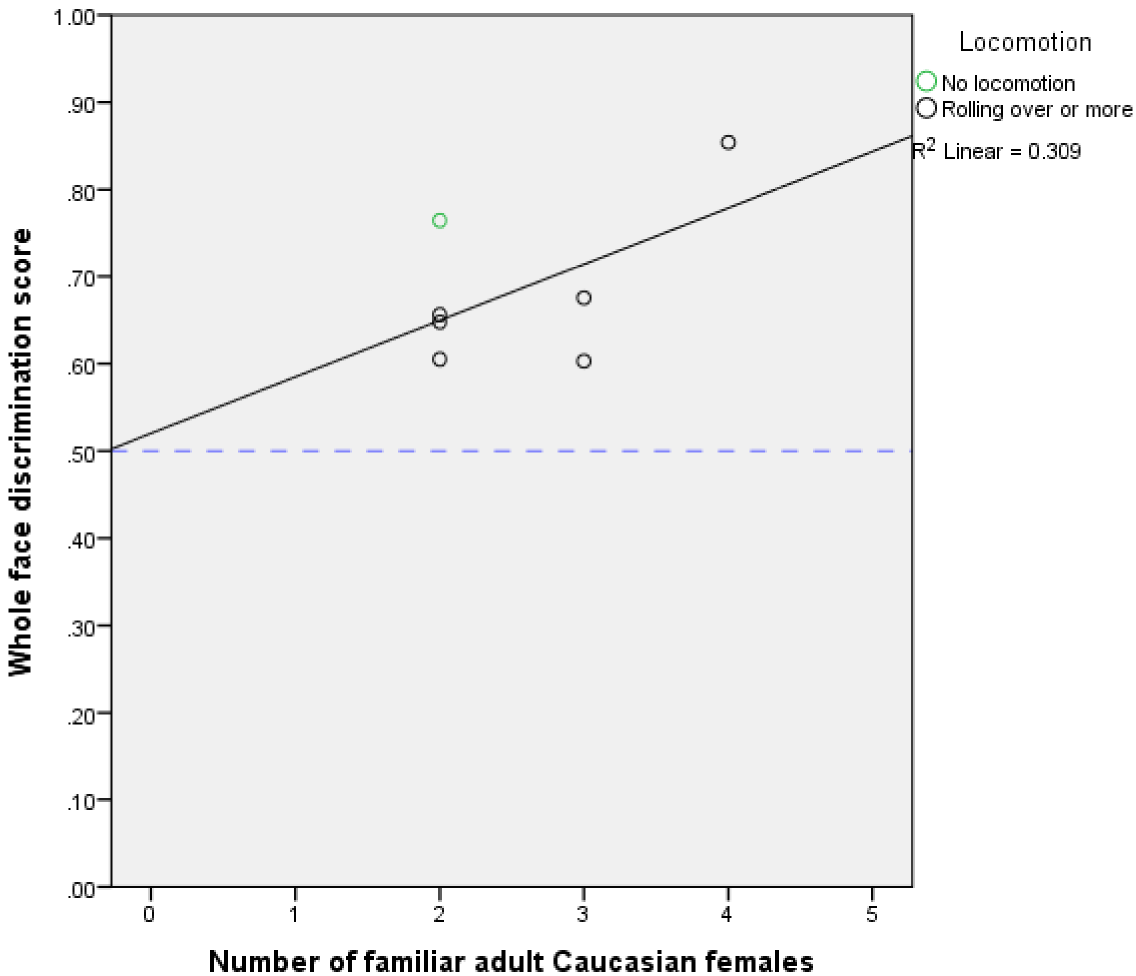

Figure 4.16. Relation between number of familiar adult Caucasian females and whole face discrimination, with locomotion marked – 7- to 8-month-old females

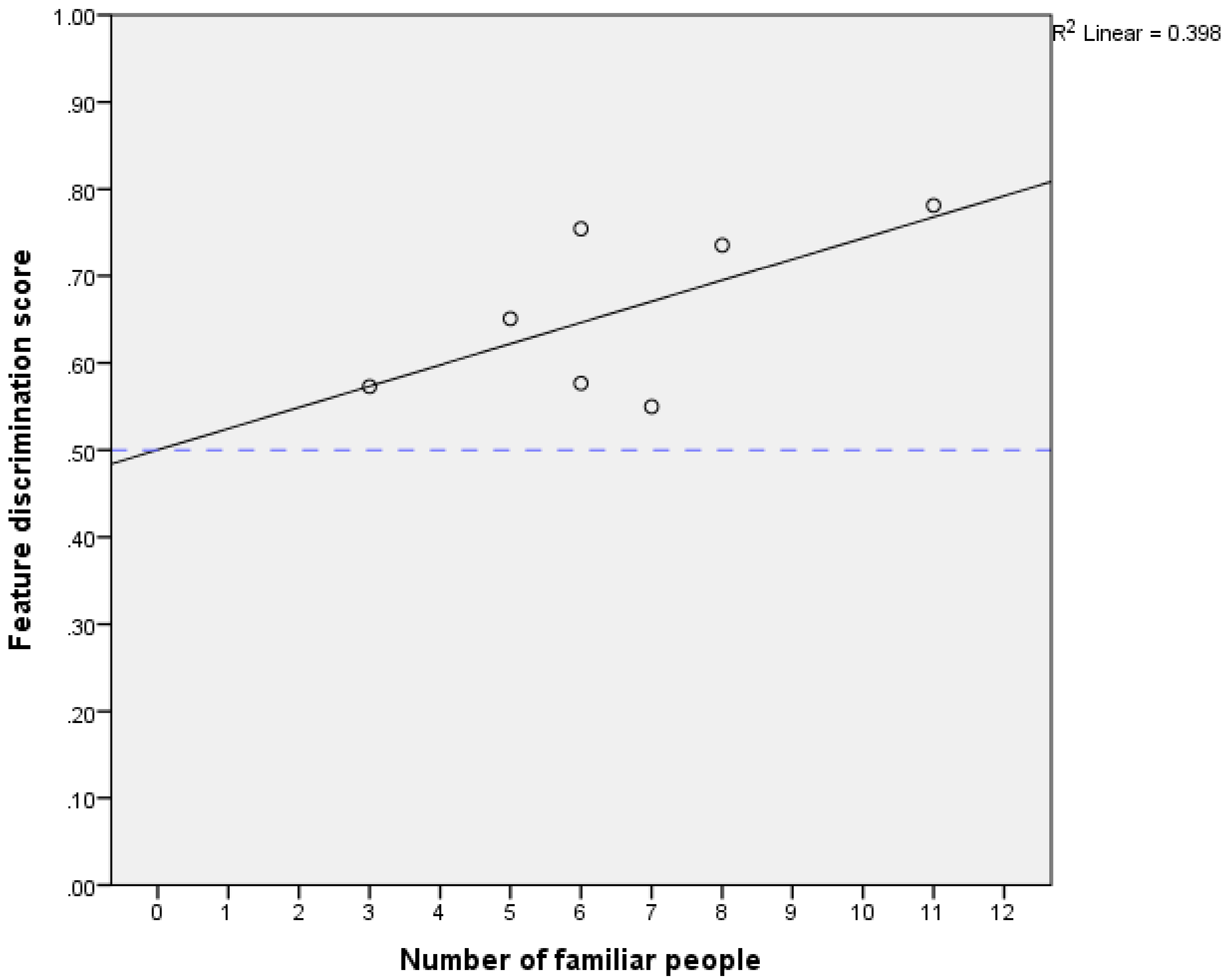

Figure 4.17. Relation between number of familiar people and feature discrimination – 7- to 8-month-old females

A3: Chapter 5 Additional Figures:

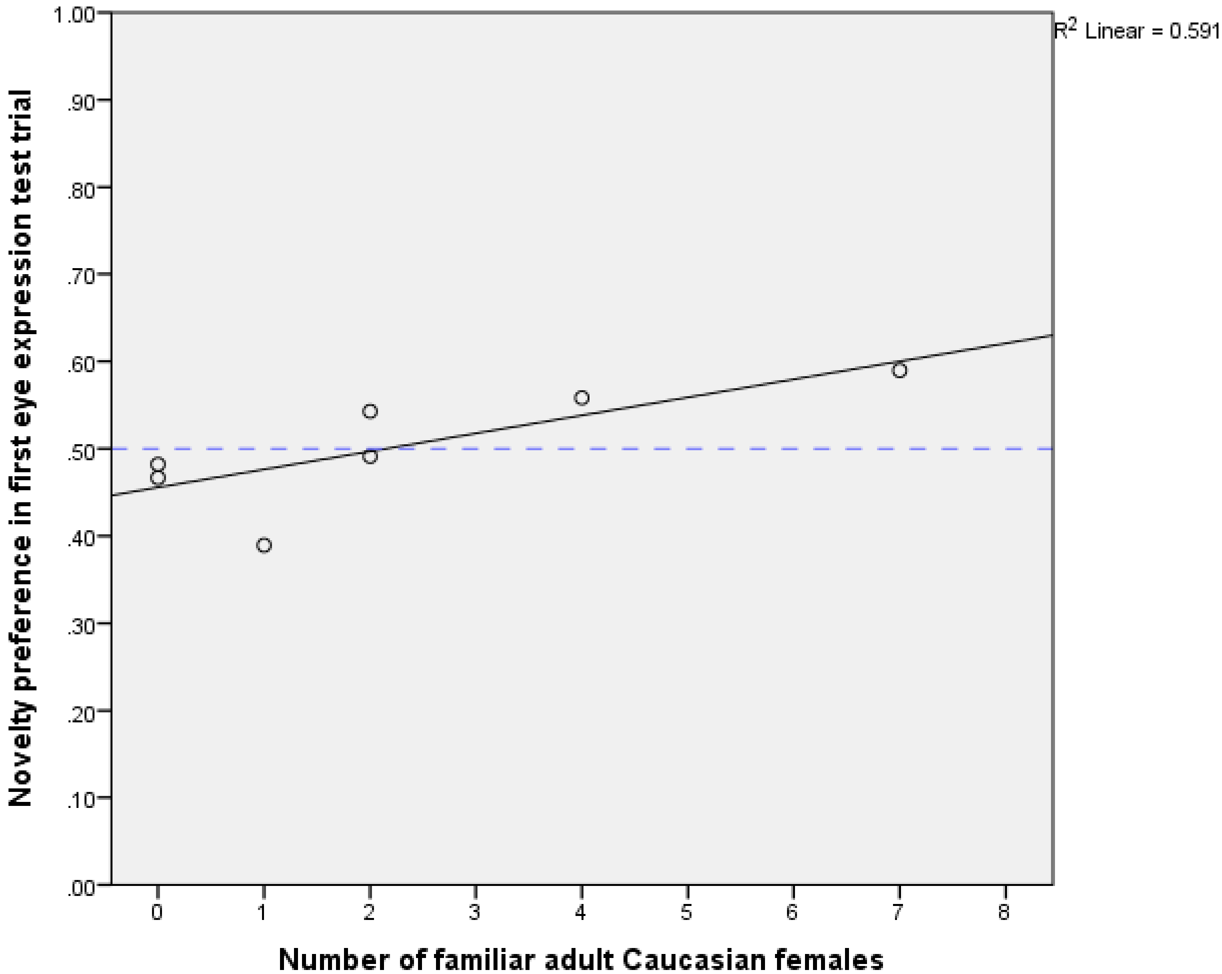

Figure 5.12. Relation between number of familiar adult Caucasian females and novelty preference in the first eye expression test trial – 5-month-old males

A4: Power Analysis:

Although the field has moved away from power calculations after the studies are complete, for the sake of completeness I have included in this appendix post-hoc power calculations for select tests in each study. The tests chosen were mostly, though not solely, tests for which the results were not statistically significant, but for which the effect size was relatively large (around 0.4 or higher) and the lack of significance may have been due to low power.

Study 2

Eye expression discrimination (5-month-olds)

In terms of the difference in means between the two sex groups, using a 1-tailed independent samples t-test to test whether the mean eye expression discrimination score of the females is significantly larger than the male mean, the power to detect the effect size of 1.0 (obtained in the study) as significant at the 0.05 level with the sample size of 10 per group used in the study, is 0.73. To obtain 0.8 power to detect this effect size (1.0) as significant at the 0.05 level, a sample size of 13 in each group is needed.

For the females, using a 1-tailed one sample t-test to test whether the mean eye expression discrimination score of the females is significantly larger than 0.5, the power to detect the effect size of 0.66 obtained in the study as significant at the 0.05 level with the sample size of 10 is 0.67. To obtain 0.8 power to detect this effect size (0.66), with alpha 0.05, using a 1-tailed t-test, the sample size required is 15.

Face identity discrimination (5-month-olds)

In terms of the difference in means between the two sex groups, using a 1-tailed independent samples t-test to test whether the mean face identity discrimination score of the females is significantly larger than the male mean, the power to detect the effect size of 0.58 obtained in the study as significant at the 0.05 level with the sample size of 10 per group used in the study, is 0.36. To obtain 0.8 power to detect this effect size (0.58) as significant at the 0.05 level, a sample size of 37 in each group is needed.

Study 3

Eye expression discrimination (7- to 8-month-olds)

For the females, using a 2-tailed one sample t-test to test whether the mean eye expression discrimination score of the females is significantly different from 0.5, the power to detect the effect size of 0.6 (obtained in the study) as significant at the 0.05 level with the sample size of 11 is 0.51 (0.63 if a 1-tailed t-test, testing whether the mean is significantly smaller than chance, were used). To obtain 0.8 power to detect this effect size (0.6), with alpha 0.05, using a 2-tailed t-test, the sample size required is 22 (18 for a 1-tailed one sample t-test testing whether the mean is significantly smaller than 0.5).

Study 4.1

Feature discrimination (5-month-olds)

In terms of the difference in means between the two sex groups, using a 1-tailed independent samples t-test to test whether the mean feature discrimination score of the females is significantly larger than the male mean, the power to detect the effect size of 1.075 obtained in the study as significant at the 0.05 level with the sample size of 8 per group used in the study, is 0.69. To obtain 0.8 power to detect this effect size (1.075) as significant at the 0.05 level, a sample size of 11 in each group is needed.

For the females, using a 1-tailed one sample t-test to test whether the mean feature discrimination score of the females is significantly larger than 0.5, the power to detect the effect size of 0.66 obtained in the study as significant at the 0.05 level with the sample size of 8 is 0.59. To obtain 0.8 power to detect this effect size (0.66), with alpha 0.05, using a 1-tailed t-test, the sample size required is 15.

Whole face discrimination (5-month-olds)

For the females, using a 1-tailed one sample t-test to test whether the mean whole face discrimination score of the females is significantly larger than 0.5, the power to detect the effect size of 0.45 obtained in the study as significant at the 0.05 level with the sample size of 8 is 0.35.

To obtain 0.8 power to detect this effect size (0.45), with alpha 0.05, using a 1-tailed t-test, the sample size required is 31.

For the males, using a 1-tailed one sample t-test to test whether the mean whole face discrimination score of the females is significantly larger than 0.5, the power to detect the effect size of 0.39 obtained in the study as significant at the 0.05 level with the sample size of 8 is 0.3. To obtain 0.8 power to detect this effect size (0.39), with alpha 0.05, using a 1-tailed t-test, the sample size required is 41.

Study 5 Part 1

Shape discrimination

For the females, using a 1-tailed one sample t-test to test whether the mean shape discrimination score of the females is significantly larger than 0.5, the power to detect the effect size of 0.48 obtained in the study as significant at the 0.05 level with the sample size of 10 is 0.45. To obtain 0.8 power to detect this effect size (0.48), with alpha 0.05, using a 1-tailed t-test, the sample size required is 27.

Study 5 Part 2

Face identity discrimination

For the males, using a 1-tailed one sample t-test to test whether the mean face identity discrimination score of the males is significantly larger than 0.5, the power to detect the effect size of 0.46 obtained in the study as significant at the 0.05 level with the sample size of 9 is 0.40. To obtain 0.8 power to detect this effect size (0.48), with alpha 0.05, using a 1-tailed t-test, the sample size required is 30.