Face Processing in Infants:
Links to Cognitive, Motor, and Socio-Emotional Development

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May 2012

Acknowledgements

First of all I would like to thank my supervisors Professor Annika Melinder PhD student Carolien Konijnenberg. By giving me the opportunity to join your project you made it possible for me to pursue a master's degree in something I believe to be truly important. I am grateful for both the theoretical guidance and the methodological help and training you have given me. Your comments on my drafts have also been highly appreciated. Thanks should also be given to all of the participants who volunteered their time to take part in this study.

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Abstract

Newborn children show an instant attraction and attention towards the faces surrounding them. This keen interest in faces stays throughout our lives. The current study investigated infant's event-related potentials (ERP) in response to familiar versus novel female faces. In addition the relation between the familiarity effect and measures of cognitive, motoric, and socio-emotional development was assessed by means of checklists and behavioral tests. Four key findings appeared: 1) Peak amplitude over the left Nc differed between the familiar and the novel face, the difference being larger for the former; 2) Peak amplitude over the right PSW differed between the familiar and novel face, the difference being larger for the latter; 3) Left Nc activation was negatively correlated with cognitive and motoric development; 4) Left PSW activation was positively correlated with socio-emotional development. These findings indicate that there is a relation between infants face processing and several behavioral measures. The results are discussed in relation to the complex development during the first year of life. This research gives insight into several possible mediators of the development of the face processing system. Uncovering these mediators is important for population groups at risk for atypical development. It may aid health care workers to spot infants at risk, as well as aiding the creation of therapies and intervention programs.

Introduction

As humans we have an expert knowledge of faces. We distinguish faces from objects, identify faces as old or young, male or female, differentiate faces of own race from faces of other race, and familiar faces from novel faces (De Haan, Johnson, & Halit, 2003). Faces can comfort, scare, instruct and guide. Faces are important for our understanding of the emotional content of a situation, or the inner feelings of a friend. The gaze of an eye directs our focus of attention.

The neural system underlying face processing is extensive and crucial for understanding our social world. As the system becomes specialized, our social understanding is improved. Deficits in the face processing system affects social aspects of life, resulting in maladjustment and social difficulties (Webb et al., 2011). This type of maladjustment can manifest in an inability to meet the demands of society, whether it may be in relation to the general public, interpersonal relationships or every-day challenges. Consequently, researchers are highly interested in understanding the neurological basis of the face processing system and its development. What are the developmental milestones? Are there critical or sensitive periods for the development? Do we all follow the same developmental trajectories? And if lost, can the ability recovered? Several models for the developmental of the face processing system have been proposed (De Schonen & Mathivet, 1989; Karmiloff-Smith, 1998; J. Morton & M. H. Johnson, 1991; Nelson, 2001). The models are supported by neurological, psychophysical and behavioral findings, which will be reviewed in this paper.

In the present study we aimed to look at the relation between infant face perception, cognitive, motoric and socio-emotional development. These are all abilities that individually contribute to our social development. Cognitive abilities assessed are related to the child's incentives to explore and manipulate objects. Motor abilities of focus are perceptual motor integration, dynamic movement and visual tracking. Finally, the social and emotional competence of the child is assessed by testing whether it seeks physical, verbal or eye-contact, or whether it is distressed and cries for long periods. There is an assumption that the child's face processing system both underlies the development within these domains as well as being affected by their function. For example, a lack of explorative tendencies towards faces or lack of interest in eye-contact may negatively affect the child's later social function by the simple fact that they are not attending to faces. Studying the developmental relation between all these domains gives a broader understanding of the face processing system.

Models on the Development of Face Processing

The nature-nurture debate comes into question for every psychological domain and the development of face processing is no exception. The initial nativist approach is that there is an innate and domain-specific ability to process faces. The focus has been on the adaptive purpose of facial recognition and infants' seemingly instant attention towards people and faces (Goren, Sarty, & Wu, 1975; J. Morton & M.H. Johnson, 1991; Nelson & Ludemann, 1989; Pascalis, De Schonen, Morton, Deruelle, & Fabregrenet, 1995). The learning theorists and empiricists on the other hand argue that there is in fact no innateness to face processing and that it is an experience-dependent ability (See review of the debate in Nelson, 2001; Thomas, 1965). In between these two contrasted camps of opinion there are other theories attempting to explain central features of child development, the neuroconstructivist approach being one of them (Karmiloff-Smith, 1998; Quartz & Sejnowski, 1997). The neuroconstructivists argue that the development of different abilities is a process initialized by genetic predispositions and then sculpted by the environment and through experience. They claim that there is an interactive process between several genes, as well as between genes and environment. The brain´s ability to adapt and show plasticity is thus what channels development. Developmental disorders, are according to this view seen as lying on a continuum, rather than being a very specific and distinct deficit from the start. A phenotype outcome could stem from only small differences in development. Research focus is therefore on early markers of change and deviation.

In the literature of face perception, there are two neuroconstructivist models of special interest in regard to the face processing system; 1) the de Schonen Model (De Schonen & Mathivet, 1989); and 2) the Johnson Model (J. Morton & M.H. Johnson, 1991). Both models argue that there exists some innate predisposition towards faces, but that experience is crucial for typical development to occur.

De Schonen & Mathivet (1989) propose a right hemisphere bias (left visual field (LVF)) towards face processing in infants and adults. The right hemisphere develops before the left (De Schonen & Mathivet, 1989), and it is better adapted towards processing stimuli with low spatial frequency. Spatial frequencies convey information of the stimulus properties. High spatial frequencies convey information of fine detail. Low spatial frequencies convey more global information, making it an important quality for infants as their visual abilities are limited (Nelson, 2001). Behavioral findings support this right hemisphere bias showing that face processing becomes more rapid when presented in the LFV(De Schonen, Mathivet, & Deruelle, 1989), and that there is greater activity over the right, compared to the left hemisphere in both infants (Dawson et al., 2002; De Haan & Nelson, 1997, 1999) and adults (Gauthier, Behrmann, & Tarr, 1999; Kanwisher, McDermott, & Chun, 1997).

Morton & Johnson (1991) focus on subcortical visuomotor mechanisms in the development of face processing. In their model they distinguish between the two processes CONSPEC and CONLERN. CONSPEC refers to a subcortical system, possibly consisting of the superior colliculus and the retinocollicular visual pathway, promoting the infants initial attention towards faces. This system is attuned to movement in the periphery and the authors argue that it in turn makes the region attuned to faces. In a more recent article it is added that a subcortical face processing route might include the superior colliculus, the pulvinar and the amygdala, offering a rapid processing of items with low spatial frequency (P. Cohen, Crawford, Johnson, & Kasen, 2005). The immaturity of the newborn cortex argues for a cortical system sensitive to the more global properties of stimuli (M.H. Johnson, 1990; J. Morton & M.H. Johnson, 1991; Nelson, 2001). After the first two months of life the importance of the subcortical regions starts to wane, and cortical systems (CONLERN) dominate the development of face processing systems. The adaption of face relevant regions in neocortex initially relies on subcortical structures, and later on experience in the further development of face processing.

Although these neoconstructivist theories point to parts of brain development that make it attractive to accept the idea of an innate but experience-dependent ability for face processing, they do lack answers to some important questions. For example, how can we prove that early (first hours of) experience is not enough to stimulate the initial ability for face processing? And how does experience "recruit" a specific brain region for its work. Nelson (2001) brings up questions such as these and focuses especially on the fact that the models do not discuss whether there is a critical versus sensitive period for the development of face processing abilities, nor how long this period must last in order for proper development to occur. A tentative answer to this question is the idea of a "perceptual window" or an "interactive specialization" (M. H. Johnson, 2005a; Lewkowicz & Ghazanfar, 2009; Nelson, 2001). The window of a sensitive period is open for development and external influence for some time and is then closed once the ability becomes more specialized and finely tuned. These tentative theories are supported by studies showing that infants between 6 and 9 months show a decrease in their ability to discriminate faces from ethnicities (Kelly et al., 2009; Kelly et al., 2007) or species (Pascalis, de Haan, & Nelson, 2002) with which they do not have frequent experience. This cross-race discrimination ability may however be kept intact through continued exposure (Pascalis et al., 2005).

What these models all strive to understand and reveal is the root to and trajectory of typical face processing development. In the next section some of the most significant structures and networks for face processing are outlined.

Neural Substrates of Face Processing in Adults

In recent years, most of the research on the neural substrate of face processing in adults has been studied using neuroimaging methods such as functional magnetic resonance imaging (fMRI). The strength of fMRI is its spatial resolution (Jezzard, Matthews, & Smith, 2001). By designing paradigms that isolate different cognitive processes, it is possible to locate specific brain regions that are activated during the given task.

The neural substrate of face processing in adults is a rather large network of brain regions reaching from the subcortical to the occipital, temporal and prefrontal (Atkinson & Adolphs, 2011). Regions in the right hemisphere have frequently been shown to elicit larger and more extensive activation in response to face processing, compared to regions in the left hemisphere (Gauthier et al., 1999; Kanwisher et al., 1997).

The primary visual cortex/striate cortex/BA17 (V1) in the occipital lobe is the initial site for cortical processing of visual information. After processing in V1, and consecutively in V2 (exstrastriate cortex/BA 18 & 19) information on the stimuli is routed in either a dorsal (V5) or ventral stream (V4) into the parietal and temporal lobes respectively. The dorsal pathway is believed to be necessary for the assessment of spatial ("where") qualities of the stimuli, whilst the ventral pathway seems more concerned with assessing "what" a stimuli represents (Kolb & Wishaw, 2006, pp. 280-281) (Kolb & Wishaw, p. 280-281). The processing of face stimuli elicits activation of the ventral network as it has a "what" quality rather than "where" (J. Haxby, 2000; J. V. Haxby, Hoffman, & Gobbini, 2000).

When viewing a face, following activation of the ventral visual pathway, information about the face is further processed by several structures in the frontal lobes. The structures most commonly reported are the dorsolateral prefrontal cortex (dlPFC) and(J. Morton & M.H. Johnson, 1991) the anterior cingulate cortex (ACC) (Reynolds & Richards, 2005). The ACC and dlPFC are two of the main structures involved in higher order functioning such as cognitive control and executive function (Bush, Luu, & Posner, 2000; Devinsky, Morrell, & Vogt, 1995; Mohanty et al., 2007). Findings from lesion studies indicate that damage to the frontal lobes increases the likelihood of false recognition of faces (Rapcsak & Edmonds, 2011) and deficits in face processing (Damasio, Tranel, & Damasio, 1990). This indicates that there is not only a bottom-up direction of face processing, but also a top-down direction wherein the occipital, temporal and frontal regions interact in the opposite manner of what is being described above.

The fusiform face area/BA37 (FFA), in the fusiform gyrus, is part of the ventral network in the temporal lobes. Other ventral areas specifically tied to the processing of faces are the occipital face area (OFA/BA19) and the face-selective region in posterior parts of superior temporal gyrus (fSTS) (Rossion et al., 2003; Yovel & Kanwisher, 2005). Studies using MR imaging find that the FFA is significantly more activated during the presentation of a face compared to the presentation of an object (Clark et al., 1996; Penn et al., 1997; Puce, Allison, Asgari, Gore, & McCarthy, 1996; Puce, Allison, Gore, & McCarthy, 1995; Sergent, Shinsuke, & MacDonald, 1992) and when presented with a proper image of a face, rather than a scrambled one (Kanwisher et al., 1997). The OFA, in combination with the FFA, seems to be specialized at distinguishing between individual faces, however, the former may be more sensitive to parts of the face rather than the face as a whole (Schiltz & Rossion, 2006). Also, the OFA shows no inversion effect (i.e. slower processing and recognition of inverted compared to upright faces) (Yovel & Kanwisher, 2005). The fSTS is found to be selectively activated by emotional expressions and gaze (J. V. Haxby et al., 2000). The fSTS also shows a robust inversion effect (Yovel & Kanwisher, 2005). Whether all three regions need to be intact for proper processing of faces is still a matter of debate (Kanwisher & Yovel, 2006; Rossion et al., 2003)

There is an ongoing discussion about whether the activity registered in FFA is a truly domain-specific mechanism specialized for face perception or whether it may be a more domain-general mechanism for processing several categories of stimuli (For a review see Kanwisher & Yovel, 2006). "The specificity hypothesis" (Kanwisher et al., 1997; Kanwisher & Yovel, 2006) argues the former view and "The individuation hypothesis" (Gauthier et al., 1999) and "The expertise hypothesis" (Gauthier, Williams, Tarr, & Tanaka, 1998) argue the latter. Theorists and researchers with a domain-general view argue that the mechanism engaged in face processing is specific for a process and not the stimuli (a face) per se. According to the individuation hypothesis a face simply recruits mechanisms for individuating and distinguishing between exemplars within a category. That is, the FFA is used as an identification tool. The argument of the expertise hypothesis in a similar manner argues that the FFA is an area for fine grained expert knowledge within a category. However, there is a continuously increasing body of literature that supports the specificity hypotheses. These hypothesis focus on neurological, behavioral and recent fMRI findings that dissociate the FFA from other nearby structures, as well as giving support to the notion that the FFA is in fact a face and not expertise-sensitive region (Duchaine & Nakayama, 2006).

Although large parts of the research on face processing have used fMRI, other methods, such as electroencephalography (EEG) are also being employed. When using EEG, the focus is more on temporal, than spatial qualities of the process at hand. The interactive activation pattern of occipital, temporal and frontal regions is thought to be the underlying structure of the registered ERP activity associated with face processing. Several ERP components have been linked to face processing. In adults the ERP components P100 (Itier & Taylor, 2002) and N170 (Bentin, Allison, Puce, Perez, & McCarthy, 1996) are linked to the detection and encoding of a face. The N170 is most visible over posterior temporal sites with a larger amplitude and longer latency in response to inverted, compared to upright faces (Bentin, Allison, Pruce, Perez, & McCarthy, 1996; De Haan, Pascalis, & Johnson, 2002) Later components such as the N250, N400 and P600 are more connected to face identification and recognition (De Haan et al., 2002; Eimer, 2000).

Based on knowledge of the fully developed face processing system existing in adults, researchers are trying to uncover the very beginning of the development of this system. Findings from face processing in infants will be reviewed in the next sections.

Face Processing as Studied in Infants

Generally on the methods used

Only minutes after birth infants show a distinct preference for faces (J. Morton & M.H. Johnson, 1991). Infants tend to move their eyes and head more towards the face-like stimuli than towards random objects and scrambled stimuli (Goren et al., 1975; M. H. Johnson, Dziurawiec, & Ellis, 1991; Mondloch et al., 1999; Pascalis & de Schonen, 1994). Recent studies have used the methods of eye-tracking and pupillometry (Anderson, Colombo, & Jill Shaddy, 2006; Gredeback, Fikke, & Melinder, 2010; Gredeback & Melinder, 2010; Gredebäck, Eriksson, Schmitow, Laeng, & Stenberg, 2012). Eye-tracking and pupillometry yield very precise information on when and where the participant is looking (Laeng, Sirois, & Gredeback, 2012). Recent methodological advances have made it possible to study psychological processes with more advanced imaging methods. PET scans have found activations the inferior temporal sulcus to be a possible precursor of the adult FFA (J. V. Haxby et al., 2000). NIRS has revealed that faces elicit a larger activation than objects in this region (Nakato et al., 2011).

For the present study, we use EEG as our main method of interest. EEG is a method commonly used in infant studies (M. H. Johnson et al., 2001; Luck, 2005; Picton et al., 2000). It is non-invasive and less demanding on the participants than other imaging techniques. The method of EEG is based on the assumption that neurons that fire during a task generate an electrical potential that is propagated to the scalp surface where it can then be measured by a series of electrodes (deRegnier, Georgieff, & Nelson, 1997 ; Luck, 2005b). The averaged EEG signal from each electrode, is what is known as an event related potential (ERP). ERP's are distinct patterns of voltage changes that occur in response to specific stimuli. The temporal resolution of ERP's is in the millisecond range, making them a great measure to get insight into the onset and duration of cognitive processes. Using the geodesic sensor net (GSN) system for electrode placement, instead of the 10-20 system the spatial qualities of the method are improving (Jasper, 1958; M. H. Johnson et al., 2001; Tucker, 1993). Early ERP components are often sensitive to physical properties of a stimuli, whilst later components are related to higher order cognitive processes such as recognition, memory and executive function (Thierry, 2005). Each component is labeled in relation to their polarity (positive (P)/negative (N)), peak latency (reported in milliseconds following stimuli presentation) and/or properties (See figure 1 for illustration). In the discussion of the results some of the most prominent challenges associated with infant EEG will be reviewed.

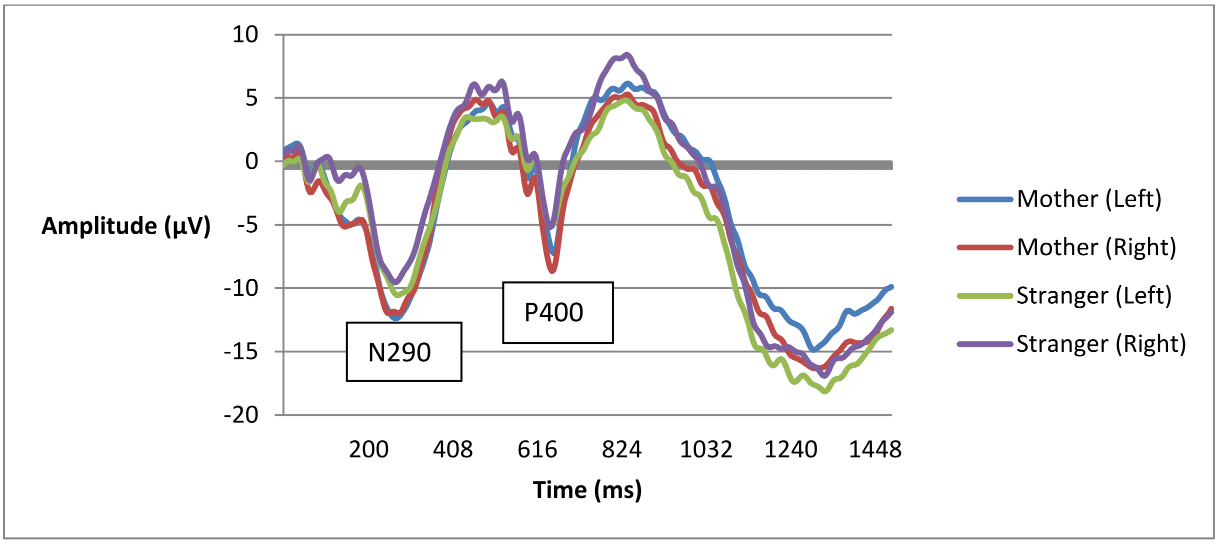

Figure 1: Illustration of ERP properties of N290 and P400. The N290 has peak negative amplitude around 290 ms after stimulus onset, and the P400 has a peak in positive direction around 400 ms.

Infant ERP Components Related to Face Processing

Several ERP components have been found to be involved in the face processing system of infants (For a review see De Haan et al., 2002). Table 1 shows a brief overview of the components of interest for the current study: N290, P400, Negative component (NC) and positive slow wave (PSW). The first two have repeatedly been related to infants' processing of the basic properties of face stimuli. They are hypothesized to be precursors of the adult N170 (Halit, Csibra, Volein, & Johnson, 2004; Halit, de Haan, & Johnson, 2003). The latter components, on the other hand, seem more related to higher cognitive processes that are linked to face processing. More specifically, they are found to be novelty/familiarity sensitive and related to memory-updating. The infant Nc shows larger amplitude for the mothers' face than a stranger's face from 6 months of age (Dawson et al., 2002; De Haan & Nelson, 1997, 1999). Contrary to Nc, the PSW generally shows larger amplitude for the stranger's face than that of the mother from 6 months of age (Dawson et al., 2002; De Haan & Nelson, 1999).

Component	Region	Deflection	Peak	Properties
N290	Posterior	Negative	125-350 ms	Involved in structural encoding, sensitive to the orientation of a face.
P400	Posterior	Positive	300-550 ms	Involved in structural encoding, sensitive to the species of a face.
Nc	Fronto-central	Negative	400-800 ms	Recognition and identification of familiar face.
PSW	Fronto-central	Positive	800-1500 ms	Updating of memory representations, sensitive to novel stimuli.

Table 1: Overview of ERP components relevant for the present study.

Processing of Familiar versus Novel Faces

Using the method of EEG, it has been found that already from the age of 3 months, children are able to distinguish between faces and objects, human and monkey faces, as well as upright and inverted faces (De Haan & Nelson, 1999; De Haan et al., 2002; Halit et al., 2003; Southgate, Csibra, Kaufman, & Johnson, 2008). There are also studies showing that infants are able to distinguish between the face of their mother and the face of a stranger (Carver et al., 2003; Dawson et al., 2002; De Haan & Nelson, 1997, 1999; Moulson, Westerlund, Fox, & Zeanah, 2009; Parker, Nelson, & Group, 2005; K. Snyder, Webb, & Nelson, 2002; K. A. Snyder, Garza, Zolot, & Kresse, 2010; Webb, Long, & Nelson, 2005).

The ability to distinguish between the face of a mother and that of a stranger is first detected around 4 months and the process seems to become more finely tuned over the first years. More specifically, the Nc amplitude is larger and the latency shorter in response to the mothers' faces compared to the strangers' in 4-6 month olds (De Haan & Nelson, 1997, 1999; Webb et al., 2005). After the first year this response seems to change towards the opposite pattern. The Nc has an increased negative deflection for the strangers' faces relative to the mothers' by 4 years of age (Carver et al., 2003; Moulson et al., 2009).

For the PSW, there is also a pattern of change. At 4-6 months (De Haan & Nelson, 1997, 1999; Webb et al., 2005) and at 3-4 years (Dawson et al., 2002) the PSW has an increased amplitude in response to the unfamiliar face. However, between 6 and 12 months(K. Snyder et al., 2002) and in a study collapsing the age group 5-31 months, this amplitude difference disappeared (Parker et al., 2005).

The change that occurs during these early years of development is possibly reflecting the infants' allocation of attention (Reynolds & Richards, 2005; Webb et al., 2011). This change can also be interpreted in relation to the underlying neurological development it reflects. The ability to recognize and identify the face likely reflects memory as well as executive processes. In order to correctly identify faces, the infant compares internal features of both faces. By keeping information in mind over a period of time these features can be compared with the information retrieved about the mother's face. In early development, the recognition process may be slow. Thus, the relatively increased activation of the Nc in young infants may reflect the additional attention that is focused towards the mother's face. However, as the prototype of the mother's face is established, this process speeds up, and increased attention towards the one or the other is no longer necessary in order to establish identity. Thus, there is a relative decline in the difference in activation following the presentation of a familiar versus novel face.

In sum, activation over the Nc and PSW can be interpreted as indirect measures of stimulus memory. The activation is believed to reflect the neural processes in structures such as the hippocampus, regions of the subcortical face processing system, and the more general social network,(M. H. Johnson, 2005b; Paterson, Heim, Friedman, Choudhury, & Benasich, 2006; Taylor, Mills, & Pang, 2011). The familiarity effect seen over these components gives insight into the specialization process of the face processing system. Knowing the onset of this ability in typically developing infants makes it possible to detect infants that may be at risk for later social difficulties. Also, it gives insight into an important milestone of face perception that may be linked to development in other domains and thereby broadens our understanding of infants' general social development.

Socio-emotional, Cognitive and Motor Development

The preference shown by infants for the familiar face has often been explained by the fact that mothers represent the most frequently available external stimulus (I. W. R. Bushnell, 2001; Sai, 2005). This is an argument supported by research on institutionalized children. Institutionalized children are able to distinguish between the face of a primary caregiver and that of a stranger. However, the level and direction of neural activation differs from that of the typically developing (Parker et al., 2005). Amongst other they show increased amplitude over the PSW in response to the mothers face and not the strangers. This pattern is thus completely opposite of the typically developing non institutionalized infants. Too little time with a primary caregiver is proposed as an explanation (Parker et al., 2005).

Webb et al. (2011) highlight the fact that for some infant groups with atypical development, such as Autism Spectrum Disorder (ASD), the initial experience with and exposure to faces is likely to be similar to that of the typically developing. They found that infants with ASD show less self-directed social experiences, that is, they direct less attention to faces in their surrounding environment. This lack of social interest might in turn lead to less exposure to-, less experience with- and thus less expert knowledge of faces (Dawson et al., 2002; Webb et al., 2011). This finding falls neatly in line with the neoconstructivist ideas of an interactive specialization of the face processing system, and it underscores the importance of experience in the social-emotional arena.

The development of several behaviors may be both directly and indirectly linked to the development of the face processing system. Social behavior and cognition has previously been found to be linked to development of grasping behavior (Sommerville, Woodward, & Needham, 2005), language acquisition (Kuhl, Tsao, & Liu, 2003), temperament (Sai, 2005) and motoric performance (E. W. Bushnell & Boudreau, 1993; D. Campos et al., 2012; J. J. Campos et al., 2000; Clearfield, 2011; Libertus & Needham, 2011; Woodward, 2009). Motor development affects the infant's social knowledge by improving skills such as distance perception, spatial search, wariness of heights and gestural communication (J. J. Campos et al., 2000). By improving motor skills the infants can change from being the recipient of stimuli, to being the approacher of desired goals. More specifically, walking, for example, increases interaction with caregivers and attention to toys (Clearfield, 2011). Interestingly it has also been found that infant groups with delayed or impaired motor abilities show abnormal social development (Osterling, Dawson, & Munson, 2002). A study correlating cognitive and motor development during the first year found a stronger correlation between the two during the latter half (D. Campos et al., 2012). That is, from 1-3 months of age there were distinct differences in performance in the cognitive and motoric domains, but from 6 months and on this difference was no longer significant (D. Campos et al., 2012). The correlation indicates that assessment of the development in one domain may yield insight into, or perhaps predict the development of other domains. It suggested that motor development may even be the necessary factor for development of more complex social skills (Libertus & Needham, 2011).

Although an ecological focus might be of great value for understanding development of the face processing system, the effect of and relation between socio-emotional, cognitive and motor development on face perception is rather unexplored (Libertus & Needham, 2011; Zebrowitz, 2006).

The Present Study

In the current study, we investigate face processing ability at six months of age and relate this development to socio-emotional, cognitive, fine- and gross-motor skills. By means of results from facial processing during EEG, a set of cognitive tests, and several questionnaires, these correlations are mapped. Components of interest are the N290 and P400 at posterior electrodes and the Nc and PSW over front-central electrodes.

The aim of this study is two-fold. Firstly, we want to test the infants' ability to distinguish between a familiar and a novel face. Secondly, we want to assess whether this differentiating skill is related to the development in other domains such as the socio-emotional, cognitive and motoric. We propose three main hypotheses; 1) Infants will show the previously noted ERP response to faces, reflected in the N290 and P400 activity over posterior electrodes (De Haan et al., 2003; De Haan & Nelson, 1999; De Haan et al., 2002; Halit et al., 2003); 2) Infants will show a different ERP response to the face of their mother versus that of a stranger at the Nc and PSW components over fronto-central electrodes (Dawson et al., 2002; De Haan & Nelson, 1997, 1999; K. Snyder et al., 2002; Webb et al., 2005); and 3) There will be a correlation between ERP responses and the infants socio-emotional, cognitive, fine- and gross-motor developmental score.

Methods

Participants

Participants were recruited from the population of Oslo. Invitations were sent out using birth lists acquired from the National Health Register. Approximately 600 invitations were sent out. Replies were received from 72 families, but as 13 replied after their child had passed 7 months, 10 were not possible to reach, and another 6 had to cancel their appointment we ended up with testing a total of 43 participants. Twenty three of the 6-month-old infants were included in the final analyses (11 females, M = 6,8 months, SD = 0,23). The 20 additional participants that were tested had to be excluded from the final analysis due to an insufficient number of artifact-free trials (N = 17) and/or fussiness (N = 3) during testing. All infants were born full term (M = 39,8, SD = 1,5). The ethnic distribution of participants was: 40 Norwegians, 1 Swedish, 1 Canadian and 1 Lithuanian. The regional ethical committee approved the study.

Stimuli

The familiar face in each pair was the face of the infant's mother. The mother's picture was taken on the day of testing in front of a white blank background. All artifacts such as earrings, jewelry and scarves were either removed prior to the photo or removed after using Photoshop. The novel faces were picked from a database of faces created for the present study. This database was constructed so that aspects such as luminance and brightness would be identical to the one taken of the infant's mother. In order to be selected, the face needed to be similar to the mothers face in terms of ethnicity, but dissimilar in other aspects such as hair and eye color. The children were presented with a total of 50 faces (25 familiar and 25 novel), and with a probability of 50% that it would be the familiar face of their mother or the novel face of a stranger. Each face was accompanied by a short sound so as to focus the child's attention towards the screen. Each face was presented for 500 ms. The inter stimulus interval was varied between 500 and 1000 ms to avoid habituation. During the inter stimulus interval the screen was white. The whole session lasted for approximately 5min.

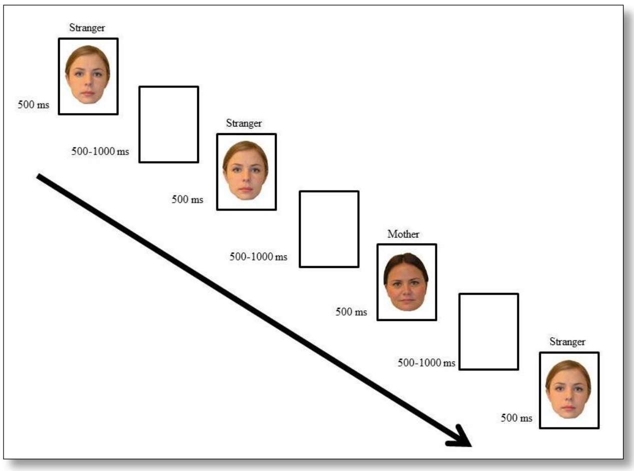

Figure 2: Stimuli.

Materials

Social-Emotional Scales

Prior to testing the infants mothers filled out two questionnaires. A *Pregnancy Questionnaire* was developed for the present study. It contained a total of 16 questions covering socio-demographic information; information about the index pregnancy; and information on the amount, dose and timing of drug exposure if any. The *Ages & Stages Socio-Emotional Questionnaire (ASQ:SE) is* concerned with the social and emotional competence of the child; whether it tends to appreciate physical, verbal or eye-contact; whether it tends to cry and show discomfort for prolonged periods and whether feeding proceeds in an expected and satisfactory manner. If the parent had any additional comments or worries concerning the child, they were given an extra page to write this down. Each statement (19 in total) was to be answered on a 3-point Likert scale (Likert, 1932), representing the answers; 1) most of the time; 2) some of the time; and 3) seldom or never. The different points on the Likert scale were given a value between one and three, stated in the provided guidelines. The total score of the questionnaire is calculated as the sum of all the items. Cronbach's alpha (Cronbach, 1951) for the ASQ:SE is .82 (ASQ:SE, 2002), indicating that the internal consistency of the test is high (Nunally, 1978), that is the items assess the same construct.

Cognitive and Motor Scales

The *Bayley Scales of Infant and Toddler Development (3rd edition)* (Bayley) (Bayley, 1993) is a standardized test covering infant and child development on a broad level and several subtests. From this test we chose to evaluate the infants on cognitive skills as well as on fine- and gross-motor skills. Skills categorized as cognitive were, for example, sensorimotor development, exploration and manipulation, concept formation and memory. Skills categorized as fine-motor were perceptual motor integration, motor planning and speed, visual tracking and reaching amongst others. Skills categorized as gross-motor skills were: static positioning, dynamic movement and quality of movement. In line with the provided guidelines, each subtest was terminated once the child had five consecutive null-scores in a row. An item was scored with the value of 0 or 1, indicating whether the required behavior/action was obtained. Total scores were computed for each of the subscales, fine- and gross-motor scores were calculated into a total motor score. Finally, total motor and cognitive scores were turned into standardized values. Cronbach's alpha for the cognitive scale ranged from .79 - .97 and the reliability of the motor scale ranged from .72 - .95 (Bayley, 2005).

Apparatus

For the EEG recording, the infants were seated 45 cm away from a 19 inch color LCD monitor (FlexScan L768) with 1280 by 1024 inches screen resolution and 32 bit color quality. A Sony Handcam (DCR HC28) was located just above the screen in order to monitor the infants looking behavior. The video was recorded through the use of NetStation software produced by Electrical Geodesics Incorporated (EGI; Eugene, OR). NetStation was also used to record the EEG data and to synchronize this with the video recordings. The experimental procedure was controlled on a Mac using E-Prime 2.0 software (Psychology Software Tools, Inc., Sharpsburg, PA). The E-prime program sent experimental events to the NetStation and utilized a single-clock system to time-lock these experimental events with the EEG and video data. Whenever the infant displayed signs of inattentiveness, the experimenter signaled to the computers to temporarily terminate the trial. During this break the screen showed pictures of animals. Once the infant refocused, the computers were signaled to continue to the next trial.

For recording the EEG signal, an EGI HydroCel Geodesic Sensor Net 2.0 of 128 Channels was used. Recordings were amplified by EGI Net Amps amplifier (Electric Geodesic Eugene, OR) and sampled at 250 Hz using the NetAmps 300 system. The vertex electrode was used as reference, for re-referencing the average reference was used. Electrolytic sponges were located within the pedestals of the net. To get the best placement of the electrodes the infants head circumference was measured and the appropriate net-size was chosen. The chosen net was soaked in an electrolytic (saline-based) solution prior to use. The solution consists of potassium chloride (KCI), warm distilled water (max 37℃), and Johnson's Baby Shampoo.

Procedure

Prior to testing, parents were given an information sheet about the purpose of the study and asked to sign and return an informed consent form. When the consent was returned, two questionnaires were sent to the parents to fill in. One was related to the pregnancy, the second asked about their impression of the socio-emotionality of their child. The questionnaires were collected at the time of testing.

Testing took place at the department of psychology at The Cognitive Developmental Research unit, EKUP. Participants were welcomed into a quiet room next to the EEG testing room. Here they were verbally informed about the purpose of the study and the procedure of the test. They were encouraged to ask questions.

The testing session consisted of two parts. The first part was the EEG recording of the infant's responses to the stimuli as described above. In order to avoid that the infant would become fussy and restless for the recording, this part was first performed. During recording, the infant was seated on the mother's lap straight in front of the computer screen. This way the mother could be in instant proximity, whilst at the same time being out of sight from the child. If the child seemed uninterested with the presented stimuli, an animal or object was presented on the screen together with its natural sound (i.e. dog barking, duck quacking). The experimenter determined if this was necessary. When one of these attention-grabbers was on the screen, the trial was temporarily paused.

Following the EEG recording, the infant was allowed a break if necessary before proceeding to the second part of the study. The second part consisted of the Bayley Test of Infant and Toddler Development (Bayley), and was performed in a separate room. Bayley was administered in order to get an assessment of the infant's general cognitive and motoric development. Due to the infants' age and the purpose of the study, only three parts of the standard Bayley test was performed: the cognitive, fine-motor and gross-motor. For the cognitive and fine-motor parts of the test, the infant was placed on the mother's lap in front of a table, and the experimenter was seated just across the table. For the gross-motor part of the test, the infant was placed on a rubber mat on the floor. During testing, the experimenter noted the child's response to the different tasks.

After testing the parents were thanked for their participation and given a gift certificate of approximately 10 euro (100 NOK). They were again encouraged to ask questions concerning the study, and to give their input if they had any.

Data Inspection

NetStation review system was used for analysis (See also Gredeback, Melinder, & Daum, 2010; Melinder, Gredeback, Westerlund, & Nelson, 2010). The highpass filter was set to 0,3Hz and lowpass to 30Hz. Stimulus period (segment) was determined as 100ms before and 1500ms after stimulus onset. For the baseline correction, each individual was controlled against him/herself, creating a baseline for comparison. For our subjects, baseline began at 100ms before stimuli presentation and is 100ms long. Artifact detection was first performed with preset rejection criteria, after which manual artifact detection was performed in order to exclude additional artifacts and trials including eye-blinks or head-movements. This is a common way to conduct artifact detection in infant studies using EEG (He, Hotson, & Trainor, 2007). Individual channels were excluded from trials if the voltage exceeded +/- 150µV. If a trial included more than 15% bad channels the trial was rejected. If an infant ended up with less than 10 good trials per category, the infant was excluded from further analysis.

Bad channel replacement was performed on the remaining good participants. Channels selected as bad were replaced by the average of the approximate channels. This is possible because of the approximation assumption that channels lying next to each other receive similar signals. After the bad channels were replaced averaging was performed, resulting in one total average of all trials for each category, per participant. Finally, average referencing and baseline correction was performed. This creates a baseline-corrected file that can be used to determine events of interest for further analysis.

In the grand-average file components of interest were determined and marked. The time windows for the different components were chosen on the basis of findings from previous empirical studies on face perception. N290:125-300ms, P400: 300-500ms, Nc: 300-500ms, PSW: 1000-1300ms. The selected time-window was verified for each individual subject to make sure that they fitted appropriately.

Statistical Analysis

In order to determine where the components of interest were best visible, the grand-average ERPs were visualized using NetStation. A topographic plot was created showing the ERP recordings in real-time. From the real-time visualization four regions were chosen; 1) Fronto-central right region; 2) Fronto-central left region; 3) Posterior right region; and 4)

Posterior left region. Each region is represented by three individual channels. Using peak amplitude as the ERP measure of interest, the chosen channels of each region were analyzed using a bivariate correlation matrix. Channel correlations are shown in table 2. Alpha level is set to 0,05.

Component	Region	Condition	Lateralisation	r	Sig
N290	Parietal	Familiar	Left	0,86	< 0,01
	Parietal	Familiar	Right	0,9	< 0,01
	Parietal	Novel	Left	0,81	< 0,01
	Parietal	Novel	Right	0,87	< 0,01
P400	Parietal	Familiar	Left	0,88	< 0,01
	Parietal	Familiar	Right	0,85	< 0,01
	Parietal	Novel	Left	0,85	< 0,01
	Parietal	Novel	Right	0,83	< 0,01
Nc	Fronto-central	Familiar	Left	0,87	< 0,01
	Fronto-central	Familiar	Right	0,71	< 0,01
	Fronto-central	Novel	Left	0,8	< 0,01
	Fronto-central	Novel	Right	0,64	< 0,01
	Fronto-central	Familiar	Left	0,64	< 0,01
PSW	Fronto-central	Familiar	Right	0,66	< 0,01
	Fronto-central	Novel	Left	0,83	< 0,01
	Fronto-central	Novel	Right	0,79	< 0,01

Table 2: Channel correlations within each region of interest.

Following the determination of components and regions of interest a script for statistical extraction was created using NetStation. Regions of interest are circled in figure 3 below. The extracted ERP data of the selected components and areas were further analyzed using SPSS (PASW Statistics 18).

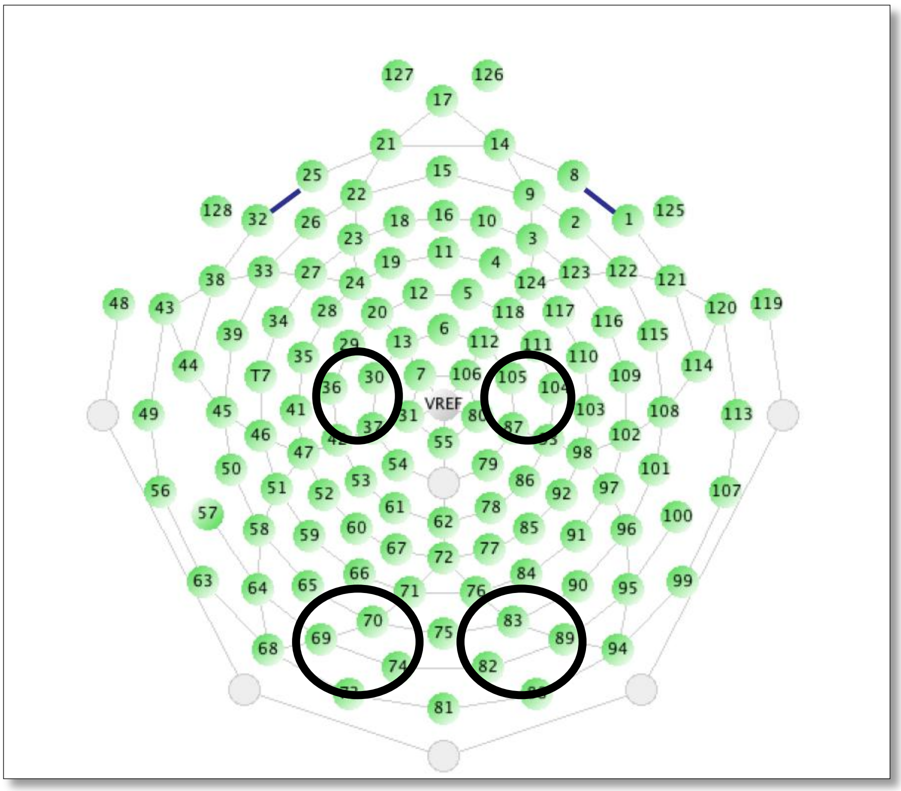

Figure 3: Illustrates regions of interest in fronto-central and posterior location. Fronto-central left and right regions include the electrodes; 36, 30, 37; and 105, 104, 87, respectively. Posterior left and right regions include the electrodes; 69, 70, 74; and 83, 89, 82, respectively.

The design of the current experiment consists of three independent measures (ERP latency, mean amplitude and peak amplitude), and three dependent measures (Condition: familiar, novel; component: N290, P400, Nc, PSW; and region: left, central, right). Separate repeated measures analysis of variance (ANOVA) were performed for each of the three chosen ERP measures, resulting in three separate 2 (Condition) X 4 (Component) X 3 (Region) within-subjects designs. Greenhouse-Geisser was used to correct for sphericity. Post-hoc paired samples t-tests were performed to assess the relations between condition, component, and region. For all analysis, the p-value of .05 was used as the criterion for statistical significance. Effect sizes are determined using Cohen's criteria and are presented as partial eta squared (J. Cohen, 1988).

All questionnaires and Bayley were scored according to provided guidelines. Using SPSS a bivariate correlation matrix was calculated using total scores from the questionnaires, Bayley, and the mean difference activation at the Nc and PSW components over the three regions. A p-value of .05 was used as the criterion for statistical significance.

Results

The aim of the present study was twofold. We wanted to see if the infants were able to distinguish between the face of their mother and that of a stranger, and whether this skill was related to development in other domains such as the cognitive, socio-emotional and motoric. We predicted that a difference in processing of the two faces would be an indication of brain maturation and cognitive development and thus positively correlated with the other developmental domains.

ERP Findings

Preliminary Analysis

To establish whether the stimuli presented were eliciting the face sensitive components, a preliminary analysis was performed. Three separate repeated measures ANOVA's were performed, one for each ERP measure. Condition (familiar, novel), component (N290, P400) and region (left, right) served as the within-subject variables of the model. Figure 4 illustrates the activation pattern following stimulus presentation over posterior electrodes.

Analyzing latency to peak, the repeated ANOVA revealed a main effect of component $F(1,22) = 190{,}30$, $p < .01$, $\eta^2 = 0{,}90$. No main effect of condition $F(1,22) = 0{,}07$, $p = 0{,}79$, $\eta^2 < 0{,}01$ or of region $F(1,22) = 2{,}56$, $p = 0{,}12$, $\eta^2 = 0{,}10$ was found. There was no interaction effect of condition, component and region $F(1, 22) = 1{,}06$, $p = 0{,}31$, $\eta^2 = 0{,}05$. Since we did not find any main or interaction effect involving condition, no post-hoc comparisons were performed for latency to peak. A similar result was found when analyzing mean amplitude. The ANOVA revealed a main effect of component $F(1, 22) = 26{,}79$, $p < .01$, $\eta^2 = 0{,}55$. No main effect of condition $F(1,22) = 0{,}94$, $p = 0{,}34$, $\eta^2 = 0{,}04$ or of region $F(1, 22) = 0{,}86$, $p = 0{,}36$, $\eta^2 = 0{,}04$ was found. There was no interaction effect of condition, component and region $F(1, 22) = 0{,}20$, $p = 0{,}66$, $\eta^2 < 0{,}01$. No post-hoc comparisons were performed for mean amplitude. Finally, analyzing peak amplitude the ANOVA revealed a main effect of component $F(1, 22) = 184{,}20$, $p < .01$, $\eta^2 = 0{,}89$. No main effect of condition $F(1,22) = 0{,}63$, $p = 0{,}44$, $\eta^2 = 0{,}03$ or of region $F(1, 22) = 0{,}59$, $p = 0{,}45$, $\eta^2 = 0{,}03$ was found. There was no interaction effect of condition, component and region $F(1, 22) = 0{,}003$, $p = 0{,}96$, $\eta^2 < 0{,}01$. No post-hoc comparisons were performed for peak amplitude.

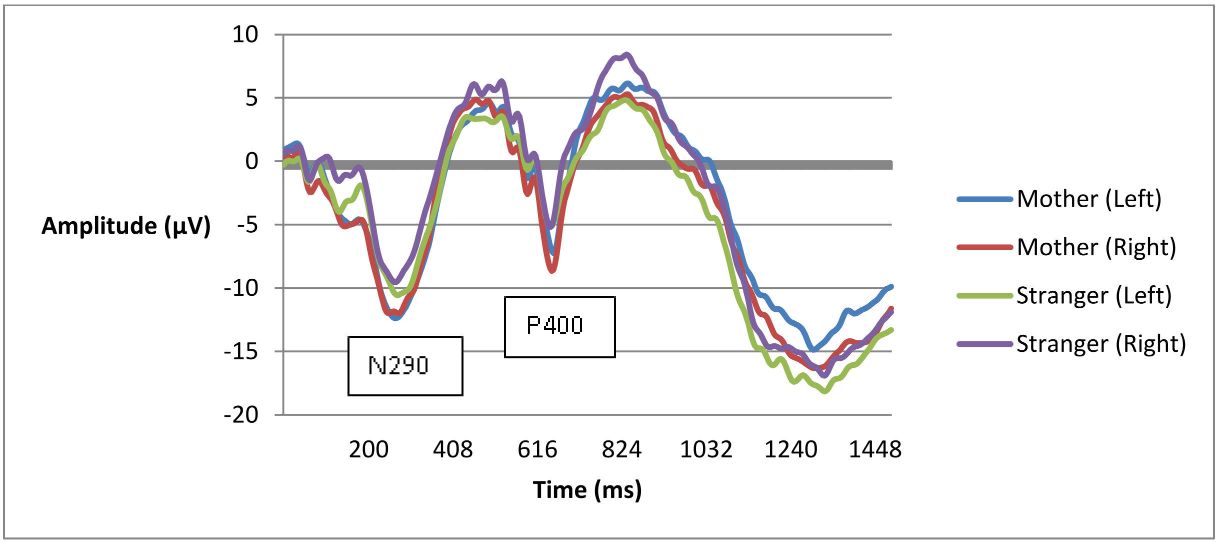

Figure 4: ERP activation pattern following stimulus presentation over posterior electrodes.

Main analysis

The main goal of this study was to find out whether the presented stimuli invoked a familiarity effect. In a similar manner to that of the preliminary analysis three separate repeated measures ANOVA's were performed, one for each ERP measure. Condition (familiar, novel), component (Nc, PSW) and region (left, right) served as the within-subject variables of the model.

Latency to Peak

Repeated measures ANOVA revealed a main effect of component F (1, 22) = 1942,52, p < .01, η^2 = 0,99. No main effect was found of condition F(1,22) = 0,66, p = 0,42, η^2 = 0,03 or of region F (1, 22) = 0,82, p = 0,38, η^2 = 0,04. There was no interaction effect of condition, component and region F (1, 22) = 0,00, p = 0,99, η^2 < 0,01. . Since we did not find any main or interaction effect involving condition, no post-hoc comparisons were performed for latency to peak.

Mean Amplitude

Repeated measures ANOVA revealed a main effect of component F (1, 22) = 72,57, p < .01, η^2 = 0,77. No main effect of condition F(1,22) = 0,11, p = 0,74, η^2 < 0,01 or of region F (1, 22) = 3,62 p = .07, η^2 = 0,14 were found. There was no interaction effect of condition, component and region F (1, 22) = 0,55, p = 0,47, η^2 = 0,02. Consequently, no post-hoc comparisons were performed for mean amplitude.

Peak Amplitude

Repeated measures ANOVA revealed a main effect of; condition F(1,22) = 12,21, $p < 0.01$, $\eta^2 = 0,36$; component F (1, 22) = 252,92, $p < .01$, $\eta^2 = 0,92$; and of region F (1, 22) = 22,09, $p < 0,01$, $\eta^2 = 0,50$. An interaction effect was seen between condition, component and region F (1, 22) = 30,63, $p < .01$, $\eta^2 = 0,58$. On the basis of significant results from the ANOVA we performed post-hoc paired samples t-tests to assess the effect of condition. The t-test revealed a significant effect of condition for the Nc over the left region of interest t(1, 22) = -2,32, p = .03, $\eta^2 = 0,10$, and for the PSW over the right t(1,22) = -6,47, $p < .01$, $\eta^2 = 0,48$. The eta squared for both the Nc and PSW indicate a strong effect, meaning that there is a substantial difference in the peak amplitude of the two components. The left region Nc peak amplitude was larger for the mothers face than for strangers. The right region PSW peak amplitude was of lager amplitude for the strangers' faces than for mothers'. When controlling for multiple t-tests using Bonferroni Correction, only the effect of condition on PSW activity remained significant. Figure 5 and 6 illustrates the activation pattern following stimulus presentation over fronto-central electrodes in right and left regions.

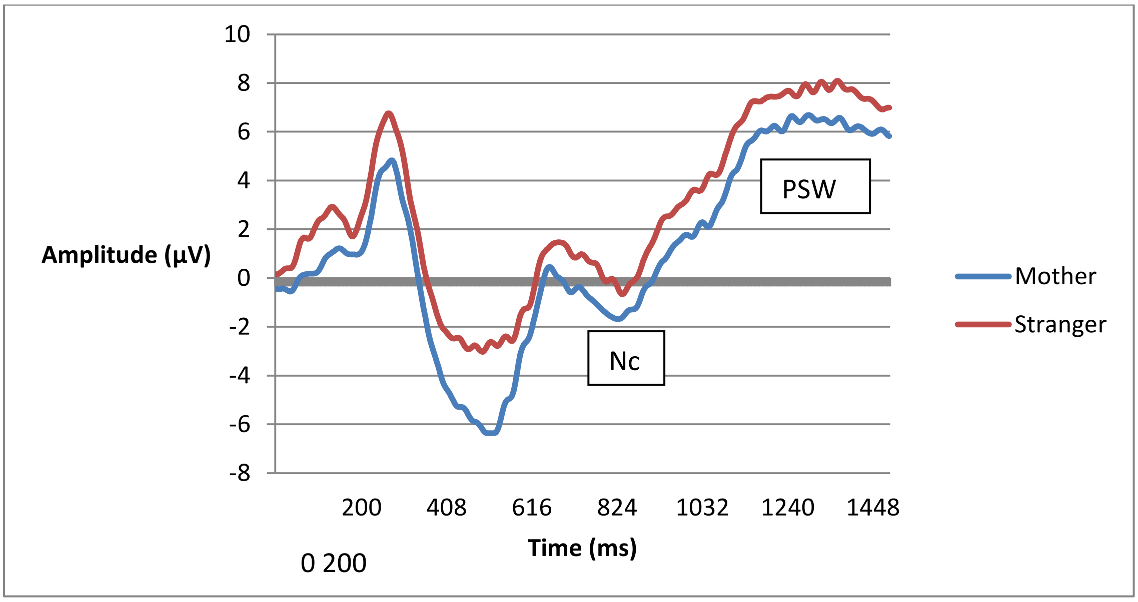

Figure 5: Illustrates ERP activity following the presentation of the face stimuli. The blue line represents the activity following the presentation of the mothers face, the red line represents the activity following the presentation of the novel face.

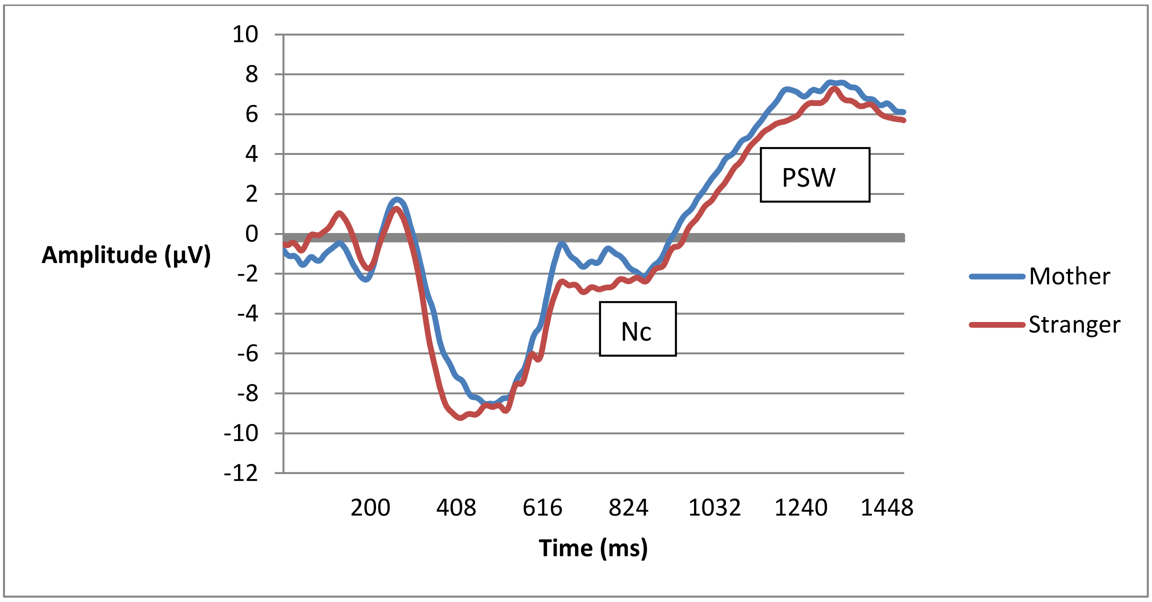

Figure 6: Illustrates ERP activity following the presentation of the face stimuli. The blue line represents the activity following the presentation of the mothers face, the red line represents the activity following the presentation of the novel face.

Behavioral Findings

The mean of total scores on the behavioral questionnaire and tests are portrayed in table 3, together with the standard deviation, minimum and maximum score.

	Mean	SD	Min	Max
ASQ:SE	12,2	8,4	0	30
Bayley Cognitive	11,43	1,85	7	15
Bayley Motor	12,17	2,3	9	19

Table 3: Illustrates infant age and total scores on each of the questionnaires.

Brain-Behavior Correlations

Using the spearman correlation coefficient the bivariate correlation matrix was calculated based on total scores from the questionnaires and the effect of condition on mean difference in activation at the Nc and PSW over the three regions of interest. The matrix is shown in table 4. The analysis revealed a negative correlation between the Bayley cognitive score as well as the Bayley motor score and the Nc activation over the left region ($p = .04$ and $p = .03$). A positive correlation was seen between the socio emotional score and the PSW over the right region (p = .04). Correlations between infant age, ASQ:SE, Bayley cognitive, Bayley motor and ERP activity over Nc and PSW are depicted in table 4.

		Nc		PSW	
		Left	Right	Left	Right
Test	Infant Age (Months)	.508	.293	.511	.927
	ASQ:SE	.249	.169	**.039***	.874
	Bayley Cognitive	**.034***	.478	.355	.685
	Bayley Motor	**.025***	.338	.377	.169

* Correlation is significant at the 0.05 level (2-tailed)

Table 4: Illustrates the correlations between ERP activation over Nc and PSW and the behavioral measures.

Discussion

Discussion of ERP Results

The preliminary aim of the present study was to see if infant ERPs are affected by the familiarity of a face. In addition we wanted to see whether this familiarity-effect would be related to the child's development in other domains such as the cognitive, motoric and socio-emotional.

From the preliminary analysis we established that there was no effect of condition on the posterior components N290 and P400 indicating that our stimuli were appropriately matched on perceptual qualities. These components are previously reported to be related to the basic stimulus properties of faces and thus should not show different activity patterns between the two stimuli presented (De Haan et al., 2003).

From the main analysis we found no main effect of condition when looking at the latency effects and this in line with previous research (Dawson et al., 2002; De Haan & Nelson, 1997, 1999; K. Snyder et al., 2002; K. A. Snyder et al., 2010). Only a few studies report mean amplitude, and amongst those who do, some find an effect of condition over the Nc and PSW (Carver et al., 2003; Parker et al., 2005; Webb et al., 2005), others do not (K. Snyder et al., 2002). Consequently, there is no clear indication that mean amplitude would show an effect of the familiar and novel stimuli.

In the present study we found an effect of condition on the Nc activity over the left region. The mother's face elicited a more negative response than the stranger's face. This is in line with previous research (De Haan & Nelson, 1997). Richards (2003b, 2003c) showed that Nc is greater in amplitude during sustained attention than during attention termination, it is thus possible to interpret from these results that the infants allocate more attention to the familiar stimuli. The Nc topography however is not in line with the previous findings as it is reported to have a right region bias. Our findings question the de Schonen model of a right hemispheric bias in infant face processing (Dawson et al., 2002; De Schonen & Mathivet, 1989). Three possible theories for this left hemispheric activation will now be outlined.

Firstly, the left hemisphere is increasingly activated when participants are instructed to match faces on selected features, whilst the right hemisphere is concerned with the face in a more voluntary manner (Hillger & Koenig, 1991; Patterson & Bradshaw, 1975; Rossion et al., 2000; Tzourio-Mazoyer et al., 2002). In the present study the infants were not instructed to match faces but it might still be that the child interpreted the situation as a task and was searching the faces in a very distinct manner in order to separate the familiar from the unfamiliar.

Secondly, there might be a connection with the language network that creates the left hemisphere activation (Coulon, Guellai, & Streri, 2011). Coulon et al. (2011) propose that the joint activation of a face and future language network shows the facilitative effect of social interactions. Other studies have found that 1, 3 and 5 month old infants are better at recognizing the face of their mother if it is presented with speech (Burnham, 1993) and recognition is further enhanced if she has talked to them before the task (Guellai, Coulon, & Streri, 2011; Sai, 2005). Also, presenting a pair of novel faces to the infant, where one of the faces is accompanied by speech sounds, results in larger activation for this face (Sai, 2005). These studies indicate that there might possibly be a speech induced/enhanced familiarity-effect. This might indicate that the left hemisphere activation seen for the Nc is partly due to the speech association the child has with the mothers face.

Finally, if we consider face processing to be an ability that develops and specializes from infancy to adulthood then there might be great individual differences in the development in this system and different age groups may be using different neural structures for face processing (Taylor et al., 2011). Face processing of familiar stimuli may activate the broader social network, especially structures related to memory updating and encoding of emotional stimuli, such as the amygdala. Thus, it may be that infants face processing causes a broader and more bilateral activation than adults. Supporting this notion is a recent study using near infrared spectroscopy on 7-8 month old infants (Nakato et al., 2011). They found that the familiar face elicited a larger reaction over the left hemisphere, suggesting a more bilateral activation for familiar stimuli.

In the present study we found a PSW right region activity . The novel face of a stranger elicited a more positive response than the familiar face of the mother. It can be interpreted from our findings that the component is sensitive to the degree of familiarity with the stimulus. Previous research on the topography of PSW activity is not unanimously pointing to a right region bias. Dawson et al. (2002) report a main effect of condition on the PSW right region activity, de Haan & Nelson (1999) report no hemispheric specificity, and de Haan & Nelson (1997) report no significant amplitude differences between the two conditions. As for the left Nc activity this lack of hemispheric specificity may be due to the "unspecialized" qualities of the infant brain.

Discussion of Behavioral Findings

Relations between behavioral scores and face-sensitive ERP components have been scarcely studied. Webb et al. (2011) has looked at correlations between scores on behavioral tests (the Mullen Scales of Early Learning (MULLEN) and Vineland Adaptive Behavior Scales (VABS)) with N290 and Nc activity. The MULLEN test assesses the child development in several domains: language, motor, cognition and perception. The VABS test, on the other hand, covers aspects of the child's social behaviors. In the present study we used similar tests by employing the Bayley test and ASQ-SE respectively. Combining the results from these behavioral tests and the familiarity-sensitive components Nc and PSW we discovered several correlations.

The Nc left region activity was negatively correlated to scores in the cognitive and motoric domains. That is, a large difference in the activation between the two is associated with lower scores in the two domains. These findings are in line with studies showing that older children elicit less or no response to the mother's face compared to that of a stranger (Carver et al., 2003; Parker et al., 2005; K. Snyder et al., 2002). This change in response patterns might signal a change in attention over the first years of life, from initially being attuned to the closest family members towards a broader social group. It also signals a great change in the infant's social development by creating a link between the ability to physically and mentally explore and an object and the desire to attend to a novel face.

The PSW left region activity was positively correlated with socio-emotional scores. This means that a larger difference in the activation between the two conditions is associated with higher scores on the socio-emotional test. Children with more developed social skills show an increased difference in response to familiar compared to novel face stimuli. Socio-emotional skills may thus be related to improved differentiating abilities (Sai, 2005).

Webb et al.(2011) argues that the reason for a link between the child's social behavior and face processing abilities lies in the common neural circuit underlying both domains, a view supported by Coulon et al.'s (2011) findings on the relation between speech and face processing abilities. Atypical or delayed development of the underlying social brain circuit would thus have a negative effect on the development of both social skills and face processing. Being born prematurely or being exposed to toxins in utero may be sources of atypicality, possibly having detrimental effects for the child's overall social development.

Discussion of EEG as Method

The method of EEG is a great imaging tool on many levels, but there are some challenges associated with it, and with infant EEG particularly; 1) High amplitude background brain activity; 2) High attrition rate; 3) Limited recording time; 4) High amplitude artifacts from abrupt movements and eye-blinks; 5) Inter-individual differences; 6) ERP components changing across the course of the experimental session. In the following sections these challenges will be outlined and discussed in relation to the present study. Some suggested improvements are also noted.

Infant EEG recordings are characterized by band activity of large amplitude (Mandelbaum et al., 2000). According to Thierry (2005) these high amplitudes become background noise when we are interested in band signal of much smaller amplitude of less mature components. Problems with these high amplitudes are best circumvented by increasing the number of trials (Picton et al. 2002). However, increasing the number of trials is not easy when the infant attention span requires short recording sessions, and even in short sessions there is a high attrition rate due to fussiness. This means that even after filtering and preprocessing of the data, some contamination may still be present.

Sources of infant artifacts are abrupt movements such as head-tilts and turns, hand-clapping, laughter, eye-blinks and eye-movements. All these artifacts can cause altered or reduced contact with the scalp over random electrode sites, at any time in any trial (Fujioka, Mourad, He, & Trainor, 2011). In adults, movement activity can be modeled and then subtracted from data using standardized procedures for artifact correction such as the independent component analysis (ICA) (Jung et al., 2000). However, in infants the movements and eye-blinks are not as systematic and temporally confined and cannot be excluded in the same modeled and automatic way (Fujioka et al., 2011). Using adult rejection criteria becomes too strict and limiting, and results in too few trials being left for final averaging . Recent methodological advances therefore suggest independent channel rejection (He et al., 2007) and artifact blocking (Mourad, Reilly, de Bruin, Rasey, & MacCrimmon, 2007) .

Independent channel rejection is a method that takes into account the infant artifact challenges by only deleting the artifact contaminated electrode channel of a trial (He et al., 2007). Electrode channels free from artifacts are kept and create the basis for averaging. This allows for artifacts to appear more randomly both in temporal and spatial distribution, whilst still keeping as many trials as possible. Caution must still be made though, as Fujioka et al. (2011) highlight, since this method might lead to spatial distortions as each trial average is based on different channels.

Artifact Blocking is a matrix based method with the main advantage being that it can be applied to signals that fail with ICA algorithms, such as infant data. A recent review assesses the advantages of traditional artifact rejection, independent channel rejection and artifact blocking (Fujioka et al., 2011). The two latter techniques are evaluated as the ones that keep the most trials, and thus yield the best data for further analysis. In the present study we preprocessed according to the principles of independent channel rejection. Differences in the stages of data preprocessing may be the source of different and sometimes contradictory findings in the literature of face processing.

Inter-individual variability of ERP components is larger in infants then in adults (Bell & Fox, 1992; Kushnerenko et al., 2002; Thierry, 2005). Great variability in brain activity may be due to either maturational differences, task performance or both. This variability may be large even in infants of very close age, possibly only weeks apart (Thierry, 2005). Longitudinal studies with infants in narrow age groups might yield insights into the finer age related changes, and would give an idea of how large an age group can be while remaining possible to average across without distorting the data.

Contrary to adult ERPs, infants ERP components may change over the course of the experiment (Stets & Reid, 2011). Stets & Reid (2011) re-analyzed previously collected data to assess how the ERP component possibly changes in amplitude and latency during the experimental trial. They performed separate ANOVAs on the data from a different number of artifact-free trials (3, 5, 7, 8, 9 and 10). Surprisingly enough, they found that the direction of activation for the conditions actually changed in polarity from the start of the experiment (i.e. 3 artifact free trials) compared to the end (10 artifact free trials). For the first three trials they found that the object-directed gaze elicited a more negative peak amplitude over the Nc component. For the first ten, the pattern was reversed. This is a change that they attribute to the cognitive process of an attentional shift. However, the finding was not significant and thus they included additional participants from the previously attritioned who had three artifact-free trials. A larger sample ought to yield more significant results (Picton 2002). And that is exactly what happened, the difference between conditions seen over the first three trials became significant. These findings suggest that research using infant EEG data can be greatly improved with; 1) Shorter experiments, as fewer trials are needed to create an average; and 2) Reduced attrition rates, as more subjects may be included, thus giving larger sample sizes. So, although most researchers strive to get a maximum number of trials to average across, the proposal that it might be sufficient with as little as three good trials per condition changes the current view on infant EEG (Stets & Reid, 2011). Finding the appropriate number of trials necessary for different paradigms, or at least combining both findings from the initial trials as well as the grand averages might be the way to go when it comes to infant EEG data.

In short, assumptions from adult ERPs may not be applicable on infant data. More specifically, there are several ways of preprocessing and analyzing EEG data from infants and a consensus should be reached in order to make findings easier to compare. In the final section, some of the main challenges for future research using infant EEG, especially related to face processing will be outlined.

Limitations of the Present Study

Attrition rates are high in studies using infant EEG. A large sample is often needed in order to get a participant group big enough for averaging. Our attrition rate was approximately 50%, a rate similar to many similar studies. The challenge of a high attrition rate may be circumvented if it turns out as Stets & Reid (2011) predict and only three trials are sufficient for averaging.

Another noteworthy point considering the group of infants tested is that they came from a sample of 600 potential participants. Thus, there seems to be a high degree of self-selection. Apart from one, all the mothers had obtained either an undergraduate or graduate university degree. Women of high socio-economic status may be of better health before, during and after pregnancy, resulting in a healthier child. They may also be more attentive towards the child, thus increasing their socio-emotional experiences and face-to-face interactions. If that is the case, socio-economic status is a factor that needs to be controlled for in studies focusing on both control and clinical infant groups.

A challenge present in any study is to isolate the cognitive process that we seek to understand and study. In relation to the present study, we need to ask whether we are in fact measuring a familiarity-effect or a mother-effect. De Haan et al. (1997) tried to tackle this issue by presenting the infants with images of two novel faces in the paradigm used in the current study. In the first experiment the novel faces were similar, in the second they were dissimilar. The analysis found no significant main effect of condition upon the ERP components of interest in any of the experiments. In the current study the stimuli consisted of a familiar and a novel face. The faces were judged to be dissimilar by the experimenter, but whether this was the case for the infant is not clear. If the stimuli for some of the participants were too similar, this may explain why some of the infants showed less distinction between the familiar and novel face. Future work needs to be directed towards creating an improvement of the classic paradigm. One possibility is to habituate the infant with the stranger's face prior to testing, time becoming an additional variable ranging from one week, to one day, to one hour in advance. Another possibility is to add speech-sound into the paradigm and present the infants with one of the two novel faces combined with speech in a habituation phase. Speech might speed up the process of familiarization.

In relation to the components of interest, there is an ongoing debate about the properties of the PSW (De Haan et al., 2003). It is both suggested to be creating representations for new faces and modifying the representations of familiar faces, as well as being a repetition-sensitive component as familiarity with a face through repeated presentations has been found to reduce the amplitude (Halit et al., 2003). Information on this issue may be gained by Analyzing the ERP averages from the beginning, middle and end of the experimental session. For the current study too few participants had enough trials for such a block analysis.

Implications for Future Work

Findings related to infant face processing and socio-emotionality gives us an ecological understanding of the infant social world. Insight is gained into visual, motoric and cognitive developmental processes. Linking face processing to social behavior has implications for treatment of children who experience social maladjustment and relational challenges.

For the future there are several points of focus. Methodological advancement with imaging techniques will yield an increasingly more nuanced and detailed picture of cognitive development. So will also the development of infant adjusted strategies for preprocessing and analysis of imaging data. Additionally, insight gained from combining imaging methods and behavioral measures will increase our understanding of developmental interrelations within the social brain network. Finally, longitudinal studies of EEG and ERP's from normal infants would yield important information about the developmental trajectory of the waves and components during the first years of life.

Conclusions

The present study aimed to explore the relationship between infants face processing and cognitive, motoric and socio-behavioral development. The results show that infants distinguish between the face of their mother and that of a stranger over the left Nc component and right PSW at fronto-central electrode sites. Left Nc activation was negatively correlated with cognitive and motoric development. Left PSW activation was positively correlated with socio-emotional development. This study is amongst the first to combine results from both imaging and behavioral data in this field. There are several interpretations and explanations for the results found, and these findings indicate a relationship that needs further exploration. There are multiple ways in which to use and benefit from this research as it creates a link between the development of the face processing system and the broader social network. Atypical development, maladjustment and social dysfunction are not uncommon. Understanding how the brain typically develops would aid the creation of therapies and intervention programs for infants that might be at risk.

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