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Neural and Behavioral Correlates of Object-Directed Attention in Early Infancy and Preschoolers

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II. Schrift

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Neural and Behavioral Correlates of Object-Directed Attention in Early Infancy and Preschoolers

1. Introduction

Imagine being a newborn and perceiving the world with all of your senses for the first time. How are infants capable of handling this conceivably enormous plenty of information and novel impressions that they encounter, given their limited capacities in memory and attention? The directed attention model of infant social cognition (DAM) (Hoehl et al., 2009; Reid & Striano, 2007, 2008) offers a framework to explain these early capacities. It describes information processing as a sequence of five stages that enable the infant to reduce the amount of input through focusing on information that is of social relevance. One crucial step in this model is Stage Four, the stage of the detection of object-directed attention. In this stage, the infant uses social cues to relate the focus of attention of an agent to objects in the environment. My dissertation concentrates on the role of eye gaze direction in Stage Four of the DAM and investigates neural and behavioral correlates of different aspects of object-directed attention in early infancy and childhood.

2. The Directed Attention Model of Infant Social Cognition

The DAM describes a sequence of five stages of information processing that allows infants to deal with a tremendous amount of input despite their limited capacities in memory and attention (Reid & Striano, 2007, 2008). Table 1 lists these stages.

Table 1

Stages of Information Processing in the DAM

Stage	Process
Stage One	The detection of socially relevant organisms
Stage Two	The identification of socially relevant organism
Stage Three	Assessment of the locus of attention
Stage Four	Detection of object directed attention
Stage Five	Interference of goals and/or prepare response

In the first stage, the individual needs to detect an organism of social relevance. The authors suggest biological motion as one crucial factor that signals the existence of a social partner. As infants right after birth are sensitive to biological motion (Simion, Regolin, & Bulf, 2008), this stage can be mastered already by newborns. Although not mentioned explicitly in the DAM, it seems plausible that other factors, like the presence of a face, may also help infants to detect a socially relevant organism (Simion, Di Giorgio, Leo, & Bardi, 2011).

In Stage Two, the detected organism needs to be identified as being a member of a certain species (e.g. a human being) or as a specific individual (e.g. the caregiver) (Reid & Striano, 2007, 2008). There is evidence that infants can manage both of these processes. At the age of 3 months, infants discriminate between faces of their own species and other species, here monkeys, on the neurophysiological level (Halit, de Haan, & Johnson, 2003). Recognizing an individual person by his/her face was mostly studied with regard to the caregiver (but see Peykarjou, Pauen, and Hoehl (2015) for individuation of strangers). Infants are able to identify their mothers right after birth (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Walton, Bower, & Bower, 1992) and show enhanced sensitivity to their mother's face (Balas et al., 2010; de Haan & Nelson, 1997, 1999), voice (Barker & Newman, 2004), and emotional expression (Kahana-Kalman & Walker-Andrews, 2001; Montague & Walker-Andrews, 2002) in their first postnatal year of life.

After identifying an agent, the infant in Stage Three can make use of specific cues like eye gaze to detect the focus of attention of the agent (Reid & Striano, 2007, 2008). Already newborns can discriminate between gazes directed at themselves and away from them (Farroni, Csibra, Simion, & Johnson, 2002; Farroni, Massaccesi, Pividori, & Johnson, 2004). Both of these two events provide important information to the infant: Being sensitive to eye contact builds the foundation for communication as it signals the infant that he/she is the addressee of an interaction (Csibra & Gergely, 2006). The authors of the DAM additionally highlight that infants are capable of adjusting their behavior depending on how the infant is involved in this interaction (Bertin & Striano, 2006; Striano, Henning, & Stahl, 2005). Detecting the focus of attention that is averted from the self can cue infants' attention to relevant information in the environment. For instance, infants as young as 3 months of age show effects of gaze cueing as their own attentional focus is shifted through the gaze direction of another person (Hood, Willen, & Driver, 1998). Furthermore, they are able to follow gaze and head cues (D'Entremont, 2000; D'Entremont, Hains, & Muir, 1997). This gaze following behavior, i.e. aligning their own gaze with another person's head or eye gaze orientation (Moore & Corkum, 1998), is supposed to be crucial for establishing joint attention situations, in which both interaction partners mutually attend to the same object (Csibra & Gergely, 2006; Morales, Mundy, & Rojas, 1998). The ability of social cues to guide infant's attention to information in the environment allows for an integration of external objects into the social situation. This enables the detection of object-directed attention in Stage Four.

3. Processing Eye Gaze Direction in Relation to Objects in Infancy

Before infants in Stage Five are able to infer goals of other people, the context broadens in Stage Four, when the focus of attention of the agent is linked to an external object (Reid & Striano, 2007, 2008). Thereby, with the help of social cues, infants' limited attention capacities can be focused on socially relevant information while irrelevant input can be suppressed. Previous research has shown that infants in their first year after birth are sensitive to the relation between eye gaze direction and external objects. Using looking times as a behavioral measure, Csibra and Volein (2008) and Senju, Csibra, and Johnson (2008) showed that infants at the age of 8 and 9 months expect gaze shifts to be referring to an object.

On the neural level, event-related potentials (ERPs) of even younger infants discriminated between object-directed and object-averted looks. The Negative Central (NC) component was enhanced in response to object-averted eye gaze in 4-month-olds but not in younger infants (Hoehl, Reid, Mooney, & Striano, 2008; Hoehl et al., 2009). The NC component is related to attentional processes (Reynolds, 2015; Reynolds & Richards, 2005). Most likely, the fact that a person was looking away from an object was more ambiguous and not expected by infants, so that more attention was allocated to process object-averted gazes. Additionally, at 4 months of age, an enhanced positive slow wave (PSW) was elicited by object-directed eye gaze (Hoehl et al., 2008). As the PSW is related to memory updating processes (Nelson, 1997; Webb, Long, & Nelson, 2005), this finding was interpreted as a facilitated forming of memory representations for cued objects compared to not cued ones.

Based on neuroimaging studies with children and adults, the superior temporal sulcus was identified as a brain area of high relevance for the processing of object-directed and object-averted gazes (Mosconi, Mack, McCarthy, & Pelphrey, 2005; Pelphrey, Singerman, Allison, & McCarthy, 2003).

The reviewed literature states an early sensitivity to eye gaze direction in relation to external objects. However, these studies used different age groups and paradigms and varied between behavioral (Csibra & Volein, 2008; Senju et al., 2008) and neural dependent measures (Hoehl et al., 2008; Hoehl et al., 2009; Mosconi et al., 2005; Pelphrey et al., 2003). Study 1 therefore applied the same paradigm to samples of infants at 2, 4, 5, and 9 months of age in a cross-sectional design to investigate the development of the underlying neural mechanisms of object-directed attention.

3.1. Study 1

Measuring induced oscillatory brain activity via electroencephalography (EEG) is for several reasons appropriate to examine the given research question. First, it can be applied already at the very young age of 2 months and is still suitable for older infants. Second, using EEG with a passive viewing paradigm does not require an overt behavior of the participant. Hence, the method is applicable for all tested age groups. With their very high resolution in the time domain, EEG data, compared to behavioral measures, reflect the actual processing of the stimulus instead of the behavioral output (de Haan & Nelson, 1997), thereby giving a more detailed hint on the processes taking place. Compared to the more frequent analysis of ERPs, induced event-related oscillations can depict processes which do not occur strictly time-locked to an event, e.g. the appearance of a stimulus on a screen (Csibra & Johnson, 2007).

In Study 1, oscillatory brain activity in response to object-directed and object-averted eye gaze was analyzed in infants aged 2, 4, 5, and 9 months. Therefore, brain activity was measured continuously applying EEG while pictures were presented to the infants showing faces that either looked toward or away from a nearby novel object. Afterwards, the EEG signal was cut in segments around the onset of the presentation of each picture. A subsequent time-frequency analysis decomposed the EEG signal based on its constituent frequencies. After averaging responses to each condition (object-averted vs. object-directed eye gaze), the oscillatory brain activity could be compared between conditions.

The theta and the alpha frequency range were of special interest for Study 1. Theta synchronization is thought to be related to an attention network that is involved in the executive control of attention (Bazhenova, Stroganova, Doussard-Roosevelt, Posikera, & Porges, 2007; Orekhova, Stroganova, & Posikera, 1999; Petersen & Posner, 2012; Posner & Petersen, 1990). This network develops between 4 and 6 months of age and monitors the relation between one’s own and other’s gaze direction (Mundy & Newell, 2007). Frontal theta synchronization decreases while the network matures (Orekhova et al., 1999). We expected this network to be the most sensitive for object-gaze relations during its development, i.e. at the age of 5 months, and be foremost responding to the disrupted relation in object-averted looks.

Alpha desynchronization is related to the suppression of irrelevant information and may thereby enable the infant to focus the attention on relevant – here cued – objects (Ward, 2003). Alpha desynchronization therefore may be a neural correlate of the process of filtering input and extracting relevant information from the environment as described in the DAM. As already 3-month-olds’ attention is shifted in the eye gaze direction of another person (Hood et al., 1998) and a month later infants are able to use gaze direction for an efficient processing of novel objects (Reid & Striano, 2005; Reid, Striano, Kaufman, & Johnson, 2004), we expected alpha desynchronization in response to faces cueing an object starting at the age of 4 months.

Michel, C., Stets, M., Parise, E., Reid, V. M., Striano, T., & Hoehl, S. (2015). Theta- and alpha-band EEG activity in response to eye gaze cues in early infancy. *NeuroImage, 118*, 576-583. doi: 10.1016/j.neuroimage.2015.06.042

As shown in Study 1, neural activity differentiates between object-directed and object-averted gaze cues by the age of 4 months and oscillatory brain activity can shed light on the development in the underlying attentional processes of social cues. At 5 months of age, infants' theta synchronization was enhanced for object-averted gaze cues. This may reflect activity from an attention network which is developing at that age and which may therefore be particularly sensitive to a disrupted eye gaze-object relation. At 4 and 9 months of age, alpha desynchronized more in response to object-directed compared to object-averted eye gaze. As alpha desynchronization is related to a suppression of irrelevant information, this result may reflect the process of filtering input to focus on socially relevant information as it is described as the goal of the information processing sequence in the DAM.

Study 1 gives some indication on the underlying neural processes and their development of object-directed attention in the first postnatal year of life. This enhances our understanding of one aspect of Stage Four of the DAM, namely the simultaneous processing of eye gaze direction as a social cue and objects in the environment. However, in Stage Four of the DAM, infants are not only required to detect the relation between an object and the attentional focus of another person, the authors also highlight the influence of social cues on infants' processing of the cued (vs. not cued) object (Reid & Striano, 2007, 2008).

4. Processing Objects Dependent on Eye Gaze Direction in Infancy

Several studies have already investigated the influence of eye gaze on object processing at the neural and the behavioral level. All of these studies used a similar paradigm, namely presenting an unfamiliar face that was either cueing an object or turning away his/her eye gaze or head from an object. Afterwards the previously cued or/and not cued object was/were presented again a second time without the face and ERPs or looking times in response to these objects were measured and compared. On the behavioral level, infants at the age of 4 months looked longer to the previously not cued object compared to the previously cued one when both objects were presented for a second time. It did not matter whether the object was cued by eye gaze alone (Hoehl, Wahl, & Pauen, 2014; Reid & Striano, 2005), by head posture and eye gaze simultaneously (Wahl, Michel, Pauen, & Hoehl, 2013) or only by head posture while eye gaze direction remained oriented toward the front (Hoehl, Wahl, et al., 2014). Results were interpreted in the following way. Social cues guided infants' attention and thereby facilitated the processing of the cued object. The processing of the not cued object however did not benefit from this attention shift and, thus, appeared more novel and therefore interesting to infants when presented again. This resulted in longer looking times to the previously not cued object. When infants at the age of 12 months were tested with a very similar paradigm, a novelty preference for the not cued object was obtained only in the first out of two test trials (Theuring, Gredebäck, & Hauf, 2007). Importantly, infants in this study were overall much longer exposed to the objects and to the cueing event than in the studies with 4-month-olds (Hoehl, Wahl, et al., 2014; Reid & Striano, 2005; Wahl et al., 2013).

The social agent in all of these studies first looked in the direction of the infant before cueing an object. Further studies adapted the paradigm in a live situation and were able to show that establishing eye contact is crucial for infants' preference for previously not cued objects. Infants at the age of 7 and 9 months, but not younger infants, showed longer looking times to the not cued objects only if the experimenter first made eye contact with the infant (Cleveland, Schug, & Striano, 2007; Cleveland & Striano, 2007).

On the neural level, activity on fronto-central or fronto-temporal electrodes was enhanced in response to previously not cued objects compared to cued ones in 4-month-olds. This was mirrored in an increased PSW (Reid et al., 2004) or an increased NC component (Hoehl, Wahl, et al., 2014; Wahl et al., 2013) in response to not cued objects. Consistent with the behavioral results, the not cued objects needed additional resources for an effective processing whereas cued objects had already been encoded more efficiently during the actual cueing.

Study 1 and the reviewed literature suggest that infants can relate eye gaze to external objects and use this social cue for their information processing at the latest at 4 months of age. Assuming a consecutive structure of the stages of the DAM allows for further predictions on factors which may influence this usage of social cues. More specifically, it can be examined how preceding stages may influence the subsequent information processing. Study 2 and Study 3 tested if a facilitated identification of an agent (Stage Two) affects the processing of object-directed attention (Stage Four) in infants (Study 2) and preschoolers (Study 3). Therefore, the socially relevant agent in these studies was either a stranger or the caregiver of the participant.

Several studies so far investigated infants' information seeking or coordinated attention to strangers and caregivers. Most of these studies presented only one agent (the familiar or the unfamiliar one) at a time because responses to both agents were either tested between-subjects (Devouche, 2004; Gredebäck, Fikke, & Melinder, 2010) or in a block design (Striano & Bertin, 2005). It was shown that infants in their first postnatal year of life engage in more gaze following and coordinated attention with strangers. In those studies, the actual identification of the agent (Stage Two of the DAM) took place only at the beginning of the experiment when infants had to identify the agent once and then spent a longer time perceiving the same agent. To challenge infants and children and to highlight the process of identifying an agent, participants in Study 2 and Study 3 were confronted with the caregiver and the stranger being the agent alternately during a short period of time. As familiar and unfamiliar faces were presented randomly, participants had to pass Stage Two of the DAM and identify the agent anew in every single trial.

4.1. Study 2

Assuming a hierarchical structure of the DAM, a facilitated identification of the individual in Stage Two may further enhance object-directed attention (Stage Four). Study 2 investigated the influence of familiarity on object processing and is, to my knowledge, the first study which addresses this question. The study used an established paradigm to examine the neural processing of objects (Hoehl, Wahl, et al., 2014; Reid et al., 2004; Wahl et al., 2013) but varied the identity of the cueing person. In a within-subjects design, infants saw either their caregiver or a stranger cueing or not cueing an object. This object was presented again and ERPs in response to this previously cued or not cued object were analyzed. Consistent with previous research, we expected enhanced activity to previously not cued objects, in particular when the caregiver acted as the social cue. The age group was set at 4 months which is in line with previous studies (Reid et al., 2004) and the result of Study 1 showing that this age may mark the onset of a more sophisticated processing of object-directed attention. We used ERPs as the dependent measure because this method is well suited for the age group and results can be very well compared and interpreted with regard to existing studies (Hoehl, Wahl, et al., 2014; Reid et al., 2004; Wahl et al., 2013). EEG was measured continuously during the stimulus presentation. Afterwards the EEG signal was cut into segments around the onset of the pictures and segments of the same condition were averaged. The emerging ERP consists of specified components which can be compared between conditions.

Hoehl, S., Wahl, S., Michel, C., & Striano, T. (2012). Effects of eye gaze cues provided by the caregiver compared to a stranger on infants' object processing. *Developmental Cognitive Neuroscience, 2*(1), 81-89. doi: 10.1016/j.dcn.2011.07.015

Results of Study 2 suggest that eye gaze direction of a caregiver's face affects the processing of novel objects to a larger degree than eye gaze direction of a stranger. A facilitated identification of the socially relevant agent may have enhanced the impact of the social cue on the processing of the object. This result is in line with the consecutive structure of the DAM.

5. The DAM in Older Children

The DAM was described as a model for infants aimed at explaining their remarkable social skills despite their limitation in memory capacities and attentional resources. The question arises how transferable the assumptions of the DAM are to older children, given the fact that during the first postnatal year infants' memory (Pelphrey et al., 2004; Reznick, Morrow, Goldman, & Snyder, 2004; Ross-sheehy, Oakes, & Luck, 2003) and attentional capacities (Colombo, 2001) increase. To examine this question, an age-appropriate measure had to be developed as not every method and not every paradigm can be transferred smoothly to another age group. This may be either because a method is no longer easily applicable, e. g. putting on an EEG cap gets more difficult with older infants (Hoehl & Wahl, 2012), or because the method or paradigm are no longer able to capture differences between conditions or specific processes as infants develop. For instance, Theuring et al. (2007) tested 12-month-olds with a very similar paradigm that Reid and Striano (2005) applied to investigate how object processing is influenced by eye gaze cues. The effect of the social cue on object processing was only replicated in the first of two test trials. This may be due to older infants' enhanced memory capacities which facilitate the encoding of novel objects, so that the same paradigm was no longer able to catch the influence of eye gaze in older children. This suggests that the paradigm used in Study 2 cannot be one-no-one applied to older children and reveals the necessity of deploying an age-appropriate task (Carlson, 2005; Garon, Smith, & Bryson, 2014). Fortunately, as infants grow older, the variety of applicable methods enlarges. As soon as infants develop language skills, they can be orally instructed to perform a certain task or they can explicitly be asked questions. With their further development in motor abilities, tasks can be expanded from passive paradigms to an active involvement of the participant. Thus, a method used to investigate a specific research question can and has to be adjusted to the age and skills of the subject.

Previous studies applied two different methods to examine eye gaze processing in children. Studies investigating the influence of eye gaze direction on attentional shifts asked children to actively press a button when a target stimulus appeared. Children's reaction times were faster when the target showed up in the direction that was previously cued by eye gaze (Ristic, Friesen, & Kingstone, 2002; Senju, Tojo, Dairoku, & Hasegawa, 2004). Thus, children's response was active (button press) and influenced by the gaze cue. However, children were not explicitly asked to provide information about the gaze direction of the person but only about the appearing target. In a second line of research, children were explicitly asked to judge the gaze direction of another person in relation to an object (see Doherty, 2006 for an overview of the literature on eye gaze judgment in children). In the looking-at-the-ball task (Doherty, Anderson, & Howieson, 2009), children had to decide which one of two faces was looking at a ball in their middle. To respond correctly, children had to relate the gaze direction to the object. It was not until the age of 4 years that the majority of children succeeded in this task. Hence, using an explicit judgment task to investigate how older children perceive eye gaze direction in relation to objects is feasible at the age of 4 years. Thus, it seems to be a useful method to shed light on how older children process eye gaze-object relations.

5.1. Study 3

In Study 3, the looking-at-the-ball task was therefore adapted and expanded to test if an enhanced identification of the agent leads to a faster judgement of the eye gaze-object relation in preschoolers. We chose to test children between 4 and 6 years as they were expected to correctly solve the task (Doherty et al., 2009). This way, we were able to introduce reaction times as a novel measure in the explicit gaze judgment literature. Assuming that children at this age are able to succeed in the task, we could measure how fast children make their correct judgments. Each child was asked to judge eye gaze direction of a stranger and of his/her caregiver. If the facilitated passing of Stage Two (identification of the agent) leads to an improved judgment of the object-related attention (Stage Four), we expected children to be faster when judging eye gaze direction of their caregiver's face.

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Preschoolers between 4 and 6 years of age needed more time to judge eye gaze direction of their caregiver's face compared to a stranger's face. The result was interpreted as reflecting more information seeking from strangers than from caregivers in this experimental situation which is in line with previous research (Walden & Kim, 2005). Study 3 suggests that preschoolers make more use of social cues of strangers than of familiar people in our experimental situation. This is opposite the result of Study 2 showing that 4-month-old infants' object processing is more influenced by eye gaze direction of their caregivers than of a stranger. It contradicts the prediction deduced from the DAM that a facilitated identification of the agent leads to enhanced (i.e. faster) processing of object-directed attention.

What does the result of Study 3 mean for the validity of the DAM in older children? It is, in my opinion, not appropriate to completely discard the model for older children. It is reasonable to assume, that preschoolers master Stage Two of the DAM and were able to quickly identify their caregivers on the photographs in Study 3. In particular, the identification of a face as belonging to someone familiar or unfamiliar (Stage Two of the DAM) did still make a difference for the subsequent processing of the object-directed attention (Stage Four of the DAM) in preschoolers as we found different reaction times in response to the caregivers' and the strangers' faces. However, the direction of the influence of the identification on further eye gaze processing differs between infants and preschoolers.

While young infants' object processing was mainly influenced by their caregiver's eye gaze direction, older children showed an enhanced detection of object-directed attention in strangers' faces.

As mentioned above, the DAM was created as a theory which may explain infants' social skills. In the model, it was assumed that the limited memory and attentional capacities of infants lead to filtering processes that enable infants to focus on relevant information. In Study 2, infants were confronted with two different agents in a short period of time. Due to their lack in processing capacities, infants may have had to reduce the amount of input in this rather complex situation. It may well be that with the help of Stage Two, infants were able to reduce the information load in focusing specifically on the social cues provided by the caregiver. Preschoolers possess enhanced information processing capacities. They may therefore not inevitably be forced to reduce or filter input and may be capable to process information provided by different agents during one experiment. Thus, even though children identified their caregiver, this may not necessarily have led to a privileged processing of the cues provided by the familiar agent. Instead, preschoolers may be able to flexibly make use of information provided by familiar and unfamiliar agents. It may be the case that children in Study 3 considered strangers as experts in this experimental situation and therefore as a reliable source of information (Walden & Kim, 2005). Further research is needed to more specifically identify situational constraints which affect infants' and children's preference to rely on information provided by different agents.

6. General Discussion

According to the DAM, infants' information processing is guided by five stages which allow infants to filter input and focus on socially relevant information despite their limited capacities in memory and attention. My thesis specifically focused on Stage Four of this information processing sequence and sheds light on the development and on familiarity as one influential factor on object-directed attention. It moreover expands the model in revealing influences between stages. Being limited in their memory and attention capacities, infants benefit from eye gaze cues to filter information and to enhance social learning processes (Study 1 and 2) while older children may be able to more flexibly use social cues to structure their environment (Study 3). Using a variety of methods and investigating several different age groups, the thesis makes an important contribution to our understanding of how infants and children use eye gaze cues to perceive and process the world. While the presented studies have in common that they investigated the role of eye gaze in object-directed attention, each study treated a slightly different research question. Therefore, several aspects have been adjusted for each study to ensure that optimal methodologies for each specific research question and age group were applied. The following paragraphs address these adjustments as well as commonalities between studies before ideas for an extension of the DAM and future perspectives will be discussed.

6.1. Methodological Differences and Commonalities of the Presented Studies

The presented studies differed with regard to the specific processes which they aimed to investigate. Study 1 and 3 examined how the relation between eye gaze direction and objects is processed or judged. Therefore, neural or behavioral responses were measured to the simultaneous presentation of the cueing face and the object. Study 2 goes one step further and examined not primarily the relation between eye gaze direction and objects but the consequence of this relation on the actual encoding of the object. Therefore, ERPs were measured not in response to the cueing event itself but to the object alone, dependent on the preceding cueing. Moreover, the studies varied with respect to the identity of the presented faces. While Study 1 focused more generally on the encoding of object-directed and object-averted eye gaze, Study 2 and 3 investigated the influence of the identification of an agent on object-directed attention. Therefore, the degree to which participants were familiar with the cueing or not cueing face was manipulated. Thus, all participants in Study 1 saw the same presentation, but in Study 2 and 3 the identity of the presented faces was customized for each subject.

Related to the specific research question is the age of the tested participants. Study 1 followed a cross-sectional design with 4 different age groups in the first postnatal year of life to investigate occurring developmental changes. Study 2 concentrated on the narrow age group of 4-month-olds with an age range of 23 days. That way, results could be compared to studies using the same age group and can give an insight into processes taking place at a highly specified age. Study 3, in contrast, selected a large age range of 4 years and 2 months to 6 years and 9 months to investigate quantitative differences in reaction times in an age group that was known to be already able to solve the task (Doherty et al., 2009). To conclude, the tested age group and age range were selected according to previous literature and the specific research question examined in the study.

Associated with the selection of the age group is the selection of the appropriate method, as not every method can be used at every age. For instance, measuring reaction times in a way it was done in Study 3 cannot be applied to young infants as they do not yet have developed the required motor skills. Vice versa, applying the relatively simple task of object processing, which was used with infants in Study 2, to older children may not be able to catch the ongoing processes due to ceiling effects (Theuring et al., 2007). Thus, the method must be adapted to the skills and capacities of a certain age group. Study 1 and Study 2 employed a neural measure using EEG. Applying a passive viewing paradigm while measuring EEG is common and reasonable to minimize artifacts in the signal due to movements (Hoehl & Wahl, 2012). The advantage of EEG is the very high resolution in time. EEG measures, thus, allow for an analysis of the actual processing of a certain stimulus in the brain. Study 1 and Study 2 differ in the way that the recorded EEG signal was analyzed. Study 1 employed induced oscillatory brain activity. Applying this method allowed us to investigate the development of two specific processes that are highly associated with Stage Four of the DAM: activity coming from an attentional network which governs the executive control of attention (theta synchronization) and the process of focusing attention on relevant input while suppressing irrelevant information (alpha desynchronization). Study 2 analyzed the EEG signal with regard to ERPs, i.e. activity measured time-locked to the appearance of a stimulus and averaged across many trials. This kind of analysis is well established in the EEG literature which allowed us to relate the results to former studies.

Adjusted to the motor abilities of each age group, infants in Study 1 and 2 participated in a passive viewing paradigm as they could hardly be asked to perform a certain task. Study 3 took advantage of the fact that preschoolers can be orally instructed and can respond with a motor action to a certain question. Hence, we employed a behavioral measure, namely reactions to decisions. On average, children needed about 2 seconds to respond. The timing is much slower than then timing of the neural processes analyzed in Study 1 and 2. One reason for this is that a behavioral measure does not reflect the actual processing of a stimulus, like EEG measures do, but depicts the result of this processing leading, for instance, to a motor response as it was the case in Study 3 (de Haan & Nelson, 1997). The behavioral measure taken in Study 3 may therefore not be able to map the exact timing of one specific process.

The current dissertation applied a variety of different measures and paradigms to investigate infants' and children's social-cognitive development. As reviewed above, several aspects were considered and adjusted to apply age-appropriate methods for specific research questions.

6.2. Extension of the DAM and Future Perspectives

The DAM provides a helpful framework to organize and integrate findings and to extract testable hypothesis. It offers a fruitful theory which will inspire future work. One promising aspect is the further examination of relations between the stages. The DAM describes the five stages of information processing separately from each other and possible influences of earlier stages on subsequent ones have mostly been neglected. But as Study 2 and Study 3 were able to show, it is indeed informative to research those relations. Therefore, the following paragraphs will explore further ideas on how early processing steps affect subsequent ones, again focusing on the impact which earlier stages may have on Stage Four.

6.2.1. Influence of Stage One on Stage Four.

As can be inferred from the DAM, a stimulus will only have an impact on object-directed attention at the fourth stage of the DAM if this stimulus is in Stage One identified as being socially relevant. Which features enable a stimulus to be detected as being of social relevance? The authors of the DAM only name biological motion as one such characteristic and review the literature showing an early sensitivity to biological motion in infancy (Reid & Striano, 2007, 2008). This characteristic is without doubt an important one and a more recent study additionally highlights the importance of biological motion for 7-month-old infants' attention and the detection of a cued target (Wronski & Daum, 2014). The impact of biological motion on the actual processing of objects has, to my knowledge, not been investigated yet and is subject to further research.

The authors of the DAM confine themselves to biological motion. But the question arises if biological motion is the only characteristic that can signal the existence of a social relevant agent and if biological motion is a necessary prerequisite for the detection of an agent. Already Nelson (2008) in his comment on the DAM pointed out the outstanding attraction of infants to faces. He highlighted that also static faces, without moving in a biological way, are attracting infants' attention. In line with Nelson (2008), Simion et al. (2011) specifically named the presence of a face besides biological motion as a characteristic that marks social agents and that can be detected by infants. Studies which show that infants right after birth are able to distinguish between face-like and non-face-like stimuli, strengthen this idea (Goren, Sarty, & Wu, 1975; M. H. Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Cassia, & Umiltà, 1996). Related to the fourth Stage of the DAM, several studies could show that also faces that were not moving in a biological manner, e.g. static pictures of faces, can influence infants' object-directed attention and object processing (see Hoehl & Pauen, 2011; Hood et al., 1998 for examples).

Intriguingly, all three studies of the current dissertation used either static pictures with already averted eye gaze (Study 1 and 3) or static pictures mimicking a gaze shift through apparent motion (Study 2). In none of these studies did the stimulus move in a biological manner, and still the stimuli influenced infants' object-directed attention. Hence, infants were able to detect the agent even without the presence of biological motion. More specifically, recent studies showed that eyes alone, without the context of a face, could influence object-directed attention in 4-month-olds. As long as an otherwise nonsocial cue comprised eyes, this cue affected infants' object processing (Michel, Wronski, Pauen, Daum, & Hoehl, 2014, July, 2014, September). It was further specified that the specific black and white contrast of sclera and pupil is crucial: Only the movement of a black dot on a white background was able to influence infants' encoding of novel objects, but not a white dot moving on a black background (Michel, Pauen, & Hoehl, 2015, March). Therefore, it may be possible to assume, that the specific black and white contrast is one feature which marks a stimulus as being of social relevance. This is in line with results showing that this contrast is characteristic for human eyes (Kobayashi & Kohshima, 1997). Additionally, reversing the contrast leads to an altered processing of faces and eye gaze (Farroni et al., 2005; Ichikawa, Otsuka, Kanazawa, Yamaguchi, & Kakigi, 2013; Jessen & Grossmann, 2014).

Contingent reactions are another characteristic inherent in the stimulus that may enable this stimulus to become a socially relevant organism to the infant. This feature was examined in the context of gaze following behavior. Performing this behavior, infants' attention can be guided to objects in the environment, thus, gaze following may enable the infant to relate the focus of attention of an agent to an external object (Stage Four of the DAM). Infants showed this behavior in response to a cue which did not feature eyes, as long as the cue reacted contingently to infants (Beier & Carey, 2014; Deligianni, Senju, Gergely, & Csibra, 2011; S. C. Johnson, 2003; S. C. Johnson, Slaughter, & Carey, 1998). To my knowledge, no research so far examined the effect of an agent that reacted contingently to the infant (Stage One) on object processing (Stage Four).

The specific influence of each of the mentioned features (biological motion, the existence of faces or eyes and contingent reactions) is not yet clear, as the agent was often featured with more than one characteristic (e.g. biological movement and eyes). Nevertheless, it can be concluded that the first stage of the DAM should be extended by additional features besides biological motion.

6.2.2. Influence of Stage Two on Stage Four.

According to Reid and Striano (2007, 2008), in Stage Two of the DAM, infants need to identify the agent. Following up on this idea, a recent study with 9-month-old infants provides first neural evidence that the processing of faces occurs stepwise, starting on a basic detection of a face on the superordinate level, followed by a more fine-grained categorization of the face as belonging to a certain species (Peykarjou, Pauen, & Hoehl, 2014). When only pictures of humans were presented, infants at the age of 9 months also showed neural indications of an individuation of a specific human being (Peykarjou et al., 2015). These studies picture well the sequential processes that are suggested to take place in Stage One and Stage Two of the DAM: detecting an agent due to the perception of a face in Stage One and subsequently identifying the agent in Stage Two as either an individual conspecific or as belonging to a certain species.

With regard to object-directed attention, the influence of the identification of an individual was examined in Study 2 and Study 3 of this dissertation. In line with the proposed information processing sequence of the DAM, results show that recognizing the identity of the agent (Stage Two) influences the processing of eye gaze in relation to objects (Stage Four). There is, to my knowledge, no other research that specifically investigated this question.

Referring to the identification of an agent as a member of a certain species, several studies addressed infants' ability to discriminate between different species, mainly monkeys and humans (de Haan, Pascalis, & Johnson, 2002; Halit et al., 2003). However, there is, as far as I know, no work examining how this discrimination will influence the way infants make use of social cues provided by different species for further information processing. For instance, would infants' attention be guided more effectively by gaze cues of a human being compared to gaze cues of a monkey? Studies that were conducted with other species in live situations showed a mixed picture. While primates are able to follow eye gaze and head turn of a human experimenter (Povinelli & Eddy, 1996), this behavior seemed to be enhanced in response to a conspecific (Tomasello, Call, & Hare, 1998). It is subject to further research whether the identification of an agent as belonging to the own species compared to a different one leads to a privileged influence of the agent on object processing. If such a facilitated learning from conspecifics exists, it might furthermore support the transmission of generic knowledge within our species (Csibra & Gergely, 2009).

6.2.3. Influence of Stage Three on Stage Four.

In the third stage of the DAM, the infant needs to detect the focus of attention of the agent and thereby is able to realize when he/she is the addressee of the communication. As Reid and Striano (2007, 2008) summarized, infants are sensitive to the focus of another person very early in their postnatal life. However, having a closer look at the model, more specific predictions can be derived on how the focus of attention of another person may influence infants' object-directed attention in Stage Four. According to the DAM, infants make use of social cues to filter information of the environment and to extract socially relevant information. Having that in mind, specifically those social cues that signal the infant that he/she is the addressee of a communication shall affect further information processing.

There are a few recent studies which investigated this idea. In those studies, infants were presented with novel objects in two different kinds of situations. The experimenter either first established eye contact with the infant and engaged him/her in a joint attention situation or presented a novel object without establishing eye contact with the infant before. In behavioral studies, 7- and 9-month-olds showed enhanced encoding of the object which was presented in the joint attention situation featuring eye contact (Cleveland et al., 2007; Cleveland & Striano, 2007). Similar results were obtained using neural measures. Infants at 5 and 9 months of age showed an enhanced NC component or more alpha desynchronization in response to objects which were presented after eye contact compared to objects which were presented without interacting with the infant (Hoehl, Michel, Reid, Parise, & Striano, 2014;

Parise, Reid, Stets, & Striano, 2008; Striano, Reid, & Hoehl, 2006). Results were interpreted as reflecting enhanced object processing in highly interactive situations. Hence, it mattered whether the focus of attention of a person was aimed at the infant or not for further information processing. This is well in line with the Natural Pedagogy account which claims that ostensive cues like eye contact signal infants that they are in the focus of attention of an agent and therefore be the addressee of information which is said to facilitate learning from conspecifics and thereby enable the transmission of cultural knowledge (Csibra & Gergely, 2006, 2009).

7. Conclusion

Imagine being a newborn and perceiving the world with all of your senses for the first time. How are infants capable of handling this conceivably enormous plenty of information and novel impressions that they encounter, given their limited capacities in memory and attention? The current dissertation adds some pieces of the puzzle which allow for a better understanding of infants' and children's social-cognitive development. It strengthens the relevance of eye gaze cues for infants' social learning processes and suggests developmental trajectories of its flexible use throughout early childhood. With growing insights into infants' perception of the social world, the fascination for infants' remarkable competencies increases all the more.

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Erklärung gemäß § 8 Abs. (1) c) und d) der Promotionsordnung der Fakultät für Verhaltens- und Empirische Kulturwissenschaften

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Theta- and alpha-band EEG activity in response to eye gaze cues in early infancy

Running title: Theta and alpha activity to gaze cues in infancy

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Abstract

In order to elucidate the development of how infants use eye gaze as a referential cue, we investigated theta and alpha oscillations in response to object-directed and object-averted eye gaze in infants aged 2, 4, 5, and 9 months. At 2 months of age, no difference between conditions was found. In 4- and 9-month-olds, alpha-band activity desynchronized more in response to faces looking at objects compared to faces looking away from objects. Theta activity in 5-month-old infants differed between conditions with more theta synchronization for object-averted eye gaze. Whereas alpha desynchronization might reflect mechanisms of early social object learning, theta is proposed to imply activity in the executive attention network. The interplay between alpha- and theta activity represents developmental changes in both kinds of processes during early infancy.

Keywords: infancy, eye gaze cues, theta synchronization, alpha desynchronization

1. Introduction

From very early on in life, eye gaze is an important cue influencing infants' perception and attention. As it helps infants to direct their attention to relevant information in the environment, eye gaze direction, among other social cues (Bertenthal, Boyer, & Harding, 2014), affects information processing and facilitates social learning (Csibra & Gergely, 2006; Hoehl et al., 2009; Reid & Striano, 2007). Here, we measure oscillatory brain activity in response to eye gaze as a referential cue in early infancy.

Infants show an early sensitivity to eye gaze direction in relation to the location of objects. Nine-month-old infants look longer to object-directed gaze shifts than to non-object-directed gaze shifts (Senju, Csibra, & Johnson, 2008). Even younger infants differentiate between object-directed and object-averted eye gaze: event-related potentials (ERPs) in response to faces looking toward objects were compared to those for faces looking away from objects in 2-, 4- and 5-month olds (Hoehl, Reid, Mooney, & Striano, 2008; Hoehl et al., 2009). Whereas no effects on the Negative central (Nc) component were found in the youngest age group, infants at 4 and 5 months showed a larger amplitude for this component for object-averted gaze. As the Nc component is related to attention (Reynolds & Richards, 2005), it was concluded that infants allocated more attention to faces that looked away from objects, because this situation was less expected and more ambiguous to them. Moreover, it was only in the 4- and not in the 5-month-olds that a larger positive slow wave (PSW) was found for object-directed looks. The PSW is related to memory updating processes (Nelson, 1997; Webb, Long, & Nelson, 2005). Thus, eye gaze may have facilitated building memory representations for cued objects. In the aforementioned cross-sectional approach, the studies by Hoehl and colleagues (2008; 2009) highlight developmental changes in the way infants process eye gaze and its relation to objects.

Similar developmental changes have been revealed by behavioral studies. Already at 3 months of age, infants are sensitive to triadic interactions (Striano & Stahl, 2005). Their ability to follow gaze shifts of strangers increases between 4 and 6 months (Gredebäck, Fikke, & Melinder, 2010). At the same time, infants' joint attention skills gradually develop (Striano & Bertin, 2005) and their ability to use social cues to encode new information advances. In a live paradigm measuring looking times, infants at 7 and 9 but not at 4 and 5 months of age showed enhanced object processing in a joint attention situation (Cleveland, Schug, & Striano, 2007; Cleveland & Striano, 2007). Studies that presented similar stimuli on a screen found that infants were able to use social cues for object learning already at 4 months (Hoehl, Wahl, & Pauen, 2014; Reid & Striano, 2005; Reid, Striano, Kaufman, & Johnson, 2004; Wahl, Michel, Pauen, & Hoehl, 2013). These studies compared ERPs and looking times in response to objects that were previously cued by another person's eye gaze and/or head turn with objects that were not cued. Cued objects were processed more efficiently whereas uncued objects were more novel to infants when they were presented to the infant a second time. This was reflected in enhanced amplitudes of either the PSW or the Nc as well as in longer looking times to previously uncued objects. Eye gaze cues guided infant attention and thereby facilitated object learning. The age discrepancy between live and video-based studies may be due to the different types of paradigms and dependent variables. A video-based presentation condenses information on a small screen and this may help infants to focus on the stimuli. The setting in a live paradigm is more complex as infants are interacting with a real person who, inevitably, covers more space. Furthermore, the dependent variable in the live studies was the overt behavior of the infant, whereas video-based studies mostly applied ERPs and/or eye tracking.

The aforementioned studies show developmental changes in the way infants make use of social cues. One possible mechanism behind these changes is how infants are able to control their attention. At 4 months of age, infants supposedly react to eye gaze cues due to an automatic shift of attention (Hoehl, Wahl, et al., 2014; Moore & Corkum, 1998). During the following two months, it has been proposed that an attention network starts to monitor and integrate infants' own and others' gaze direction and behavior. Between 7- and 9-months, infants are able to internally control their shifts of attention (Mundy & Newell, 2007; Petersen & Posner, 2012).

As results of studies investigating the use of social cues differ depending on the paradigm used, the current study makes use of the same paradigm for all age groups in a cross-sectional design with infants aged 2, 4, 5, and 9 months. As in the study by Hoehl et al. (2008), infants saw static images of faces either looking toward or away from an object while their EEG was measured. So far, the neural processing of eye gaze–object relations in infancy has only been investigated using ERPs. In the current study we analyze oscillatory changes to further clarify underlying neural mechanisms of how social information is processed.

Based on the literature, the alpha- and the theta-band are likely to be sensitive to eye gaze-object relations: Theta-band activity in adults lies between 4 and about 7 Hz (Klimesch, 1999; Saby & Marshall, 2012). Theta in infants, that we refer to in the current study, is primarily defined between 3 and 6 Hz and the frequency range does not seem to change between 4 and 12 months (Saby & Marshall, 2012; Stroganova & Orekhova, 2007). Theta synchronization may imply activity of the frontal cortex including an attention network involved in executive and voluntary control of attention as it has been proposed by Posner and Petersen (Bazhenova, Stroganova, Doussard-Roosevelt, Posikera, & Porges, 2007; Orekhova, Stroganova, & Posikera, 1999; Petersen & Posner, 2012; Posner & Petersen, 1990). It has been suggested that this attention system emerges at around 4-6 months and allows infants to monitor the relation between their own and others' gaze direction and goal-directed behavior (Mundy & Newell, 2007). Frontal theta activity decreases with age. This decrease is proposed to reflect maturation processes in the attention system as the system gets increasingly effective (Orekhova et al., 1999). If theta activity implies executive control of attention, it would be expected to vary with developmental changes in response to social cues. Therefore, we expect to find no differences between conditions in theta synchronization in the 2- and 4-month olds as the executive attention network should not be developed yet. In 9-month-olds, the network should have matured and be more efficiently functioning (Orekhova et al., 1999). As theta decreases in older infants, we expect little or no difference in theta synchronization between conditions. Changes in theta activity may reflect the development of this system which occurs at around 5-6 months of age and we therefore expect theta effects specifically in this age group.

Alpha desynchronization in adults has been related to attentional mechanisms that actively suppress distracting information to focus on relevant input (Ward, 2003). In a live triadic joint attention interaction, Lachat, Hugueville, Lemaréchal, Conty, and George (2012) reported attenuated alpha signal power (11-13 Hz) in adult participants that jointly attended to the same stimulus. This result was interpreted as reflecting higher arousal induced by mutual attentiveness. Hoehl, Michel, Reid, Parise, and Striano (2014) recently showed similar effects in 9-month-old infants in a live paradigm. Here, alpha (5-7 Hz) desynchronized in response to novel objects only when these objects were presented in a joint attention situation (Hoehl, Michel, et al., 2014), indicating that alpha-band activity varied depending on the social context in which stimuli were perceived. Alpha desynchronization was therefore suggested to relate to early social learning processes in infants (Hoehl, Michel, et al., 2014). Enhanced alpha desynchronization may indicate that attention is focused on the relevant object (here an object that is cued by eye gaze). Thereby it could enable or at least facilitate object learning in such situations. Similar processes might take place already at 4 months as infants differentiate between eye gazes toward and away from objects and build stronger memory representations for cued objects (Hoehl et al., 2008; Hoehl, Wahl, et al., 2014; Reid & Striano, 2005; Reid et al., 2004; Wahl et al., 2013). In the current study, eye gaze that is directed toward an object identifies it as an object that is of high relevance for the infant. Thus, we expect desynchronization to occur in response to object-directed gaze starting at 4 months of age in the alpha-band frequency range 4-10 Hz, which is the typical range for alpha in infants (Marshall, Bar-Haim, & Fox, 2002; Stroganova, Orekhova, & Posikera, 1999).

The current study investigates oscillatory brain activity in response to object-directed and object-averted eye gaze for synchronization in the theta range and for desynchronization in the alpha range. By studying 2-, 4-, 5-, and 9- month-old infants with the same paradigm, we expect to gain insights into how the processing of social cues develops and how attentional and social information processes change in early infancy (Cleveland et al., 2007; Cleveland & Striano, 2007; Striano & Stahl, 2005).

2. Method

2.1 Participants

The final sample consisted of 58 (32 female) 2-, 4-, 5-, and 9- month-old infants born full term (37-41 weeks) and within the normal range for birth weight (see Table 1 for detailed information about age, sex, and the number of trials included in the final analyses separately for each age group).

Another 79 infants were tested but excluded from the final sample due to fussiness (17) or failure to reach the minimum criterion of 10 artifact-free trials per condition (62). This inclusion criterion and the attrition rate of 58% are similar to other infant EEG studies (e.g. Elsabbagh et al., 2009; Southgate, Csibra, Kaufman, & Johnson, 2008). Data of 14 additional infants were distorted due to technical problems and, therefore, not analyzed. The group of 4-

month-old infants consists of the sample reported in Hoehl et al. (2008) and the group of 2- and 5-month-olds of the sample reported in Hoehl et al. (2009). Both of these studies investigated ERP effects. On average, infants contributed 20 artifact-free trials to the grand average per condition.

Table 1. Sample information and overview of included trials per condition.

	2-month-olds	4-month-olds	5-month-olds	9-month-olds
N	14	16	16	12
Sex	10 female	8 female	7 female	7 female
Mean age (mm.dd)	02.23	04.02	05.19	08.28
Age range (mm.dd – mm.dd)	02.07 – 03.00	03.21 – 04.09	05.02 – 05.29	08.21 – 09.09
Mean number; standard deviation (range) of included trials: object-directed condition	27; 16 (10-63)	19; 7 (10-37)	19; 10 (10-41)	14; 3 (10-20)
Mean number; standard deviation (range) of included trials: object-averted condition	27; 16 (10-62)	19; 8 (10-37)	20; 10 (10-41)	14; 3 (10-20)

2.2 Stimuli

Static portrait photographs of two female actors served as stimuli. Their eye gaze was shifted either to the left or to the right and a colorful object was presented next to the face on one side at the height of the pupils approximately 2 cm away from the eyes. Consequently, two different conditions were created: in the *object-directed condition,* the actor looked at the object and in the *object-averted condition,* the actor looked away from the object (see Figure

1). Stimuli were 19.5 cm (12.4° visual angle) high and 25 cm (15.8° visual angle) wide measured from the ear of the actor to the end of the object on the opposite side.

(Figure 1 about here)

2.3 Procedure

During testing, infants sat on their mother's lap while their EEG was recorded continuously and their behavior was filmed for offline coding. Stimuli were presented on a 70 Hz 17'' screen at 90 cm viewing distance in a dimly lit, sound-attenuated, and electrically shielded cabin.

A trial consisted of a central attractor (a small triangular object) presented at the center of the screen for 500 ms followed by a stimulus image presented for 1000 ms. Before the next trial started, a white screen was presented with a random interval of 800 – 1000 ms (see Figure 1). Conditions were presented in a randomized order with the constraint that each condition was not presented more than twice in a row and the number of object-directed and object-averted pictures was balanced every 20 trials. A maximum number of 200 trials (100 per condition) was presented as long as the infant looked attentively to the screen. Testing was paused or stopped if the infant became fussy or inattentive to the screen.

2.4 EEG recording and analyses

EEG was recorded continuously during testing with 19 Ag-AgCl electrodes arranged according to the 10-20 system. Data were amplified via a Twente Medical System 32-channel REFA amplifier and sampling rate was set at 250 Hz. Data were analyzed using the custom made scripts collection "WTools" (available on request) and EEGLab (v. 10.2.5.5a). EEG was referenced to the vertex (Cz). Horizontal and vertical electrooculograms (EOG) were recorded bipolarly. Data were re-referenced offline to the averaged mastoids and were bandpass filtered from 2 to 65 Hz. The EEG signal was segmented into epochs of -1200 ms to 2000 ms around the onset of the stimulus. EEG data were rejected offline whenever the standard deviation within a 200 ms gliding window exceeded 80 µV at any electrode (Hoehl et al., 2008). Artifacts caused by eye movement were rejected based on EOG measures. Infants' looking behavior was coded offline based on the recorded videos. Trials in which the infant did not attend to the screen were removed manually. Given that infants overtly shifted their eye gaze during the presentation of the stimulus image in only 7.97% of all presented trials, we did not analyze this behavior further.

Time-frequency analyses were conducted performing a continuous wavelet transformation. Complex Morlet wavelets were computed at 1 Hz frequency intervals for the frequency range 2 – 60 Hz. Total spectral activity was calculated performing convolutions with the wavelets on all channels. The absolute value of the result was computed and served as the dependent variable. The transformed epochs were averaged for each condition (see Csibra, Davis, Spratling, & Johnson, 2000; Hoehl, Michel, et al., 2014; Parise & Csibra, 2013). Furthermore, 1000 ms at the beginning and at the end of each segment were removed to avoid distortions due to the transformation. Baseline correction was performed at each frequency by subtracting the mean activity of 200 ms before stimulus onset from the signal.

The grand average was calculated for both conditions for each age group separately. The time-frequency range for statistical analyses for the theta and the alpha frequency range was based on visual inspection of the data and existing literature.

2.5 Theta activity

Visual inspection of the data revealed differences between conditions mainly in the lower frequency range. The theta 1 sub-band was defined as ranging between 3.6 and 4.8 Hz with a peak at 4.4 Hz (Orekhova, Stroganova, Posikera, & Elam, 2006). Theta activity in this frequency range is more pronounced on frontal channels (Orekhova et al., 1999; Orekhova et al., 2006; Stroganova, Orekhova, & Posikera, 1998). Compared to alpha activity, the theta frequency range does not seem to shift with age (Saby & Marshall, 2012; Stroganova & Orekhova, 2007). Thus, the mean amplitude at 4 Hz at 400-800 ms after stimulus onset on fronto-central electrodes (F3, Fz, F4, FC3, and FC4) served as the dependent variable for all age groups (Orekhova et al., 2006).

2.6 Alpha activity

In infancy, alpha occurs on posterior-occipital channels in the frequency range 4-10 Hz with an increase in frequency with age (Marshall et al., 2002; Stroganova et al., 1999). Therefore, the time-frequency range for the analyses was chosen for each age group separately based on visual inspection of the differences between conditions. Mean amplitude of P3, Pz, P4, O1, and O2 served as the dependent variable. Consistent with the literature, the selected frequencies increased with age (Marshall et al., 2002; Stroganova et al., 1999). See Table 3 in the results section for an overview of the time-frequency ranges.

As no differences between channels are expected, the amplitude of the frontal channels F3, Fz, F4, FC3, and FC4 was averaged for theta activity and the amplitude of the posterior-occipital channels P3, Pz, P4, O1, and O2 was averaged for alpha activity for each condition. The two conditions were contrasted using paired t-tests separately for each age group. P-values are Bonferroni-Holm corrected.

3. Results

3.1 Theta

No significant differences between conditions were found for the 2-, 4-, and 9-month-olds, all *p*s > .431. However, the object-averted condition and the object-directed-condition differed significantly in the 5-month-olds, t (15) = -3.50, p = .012. Theta synchronized more in the object-averted compared to the object-directed condition. Theta activity in both conditions did not differ from baseline, all ps > .195. See Figure 2 and Table 2 for means and standard errors.

Table 2. Overview of the time range, the frequency and descriptive statistics of the analyses of theta activity.

theta	2-month-olds	4-month-olds	5-month-olds	9-month-olds
Time range	400-800ms	400-800ms	400-800ms	400-800ms
Frequency	4 Hz	4 Hz	4 Hz	4 Hz
Mean (standard error) object-directed condition [µV]	-0.32 (0.08)	-0.37 (0.08)	-0.23 (0.15)	-0.44 (0.18)
Mean (standard error) object-averted condition [µV]	-0.24 (0.11)	-0.30 (0.11)	0.38 (0.19)	-0.14 (0.29)

---- Figure 2 about here ----

3.2 Alpha

Whereas alpha activity in the object-directed and the object-averted condition was not different in the 2- and 5-month age groups (all ps > .619), there were significant differences between the conditions at the ages of 4 and 9 months (t (15) = -3.46, p = .008 for the 4-month-olds, t (11) = -2.73, p = .038 for the 9-month olds). While both conditions in both age groups differed significantly from baseline (4-month-olds: t (15) = -7.22, p < .001 for the object-directed condition and t (15) = -3.65, p = .006 for the object-averted condition; 9-month-olds: t (11) = -6.01, p < .001 for the object-directed condition and t (11) = -3.50, p = .015 for the object-averted condition), the desynchronization was enhanced in the object-directed compared to the object-averted condition at both ages. See Figure 3 and Table 3 for an overview of the means and standard errors.

Table 3. Overview of the time and frequency ranges and descriptive statistics of the analyses of alpha activity.

alpha	2-month-olds	4-month-olds	5-month-olds	9-month-olds
Time range	400-800ms	400-800ms	400-800ms	200-800ms
Frequency range	5-7Hz	5-8Hz	5-8Hz	6-8Hz
Mean (standard error) object-directed condition [µV]	-0.22 (0.08)	-0.53 (0.07)	-0.46 (0.17)	-0.89 (0.15)
Mean (standard error) object-averted condition [µV]	-0.07 (0.09)	-0.34 (0.09)	-0.40 (0.15)	-0.47 (0.13)

---- Figure 3 about here ----

4. Discussion

In order to investigate developmental changes in neural mechanisms underlying the processing of eye gaze-object relations in early infancy, we presented infants (2, 4, 5, and 9 months old) with faces that were either looking away from or toward objects while EEG was measured. Differences between conditions in the theta and the alpha frequency bands were investigated for each age group. In line with studies showing that 4-8-month-old infants differentiate between object-directed and object-averted gaze shifts with regard to looking times and ERPs (Hoehl et al., 2008; Hoehl et al., 2009; Senju et al., 2008), we have shown that theta and alpha oscillations are sensitive measures to investigate this social cognitive ability in these age groups.

Theta synchronization is suggested to reflect the involvement of an executive attention network and internal attentional processes (Bazhenova et al., 2007; Orekhova et al., 1999). We expected theta activity to alter with the development of this network. We found differences between conditions only in the 5-month-old infants. At that age this attention network is thought to develop (Mundy & Newell, 2007). Theta activity synchronized more in the object-averted than in the object-directed condition. It is important to note that theta activity in the 5-month-olds did not differ from baseline. The difference in theta synchronization between conditions must therefore be interpreted very cautiously.

Alpha desynchronization has been shown to be sensitive to attentional mechanisms that enable the brain to suppress irrelevant input and focus on relevant information in adults (Ward, 2003). Cues such as eye gaze signal objects that can be relevant for a beholder (Frischen, Bayliss, & Tipper, 2007; George & Conty, 2008; Hoehl et al., 2009; Senju & Johnson, 2009). Enhanced alpha desynchronization may reflect the attentive processing of such information. We speculate that it, as such, enables or facilitates early social learning mechanisms in infants. This is in line with studies that relate alpha desynchronization to joint attention in infants and adults (Hoehl, Michel, et al., 2014; Lachat et al., 2012). As infants at 4 months of age are already sensitive to looker-object relations and use eye gaze for facilitated object learning (e.g., Reid et al., 2004), we expected alpha desynchronization in response to object-directed eye gaze from 4 months onwards. This expectation was partly fulfilled as alpha desynchronized more in the object-directed condition in 4- and 9-month-olds, but not at 2 and 5 months of age. Taken together with the results on theta activity, substantial developmental changes in the neural processing of object-looker relation have been detected in the current study.

As we did not find a difference between conditions on both frequency bands at 2 months of age, we can only speculate about the neural processes occurring at this age. Infants at this age show nearly no overt gaze following behavior. The tendency to follow another person's gaze, and, therefore, the ability to detect object-looker relations, develops between 2 and 4 months of age (Gredebäck et al., 2010). Thus, infants at 2 months of age might simply not detect differences between conditions. Alternatively, it is possible that infants are able to differentiate between the conditions but our methodology was not capable of detecting this. In line with the current results, no ERP effects have been observed using the same stimuli in 2-month-olds (Hoehl et al., 2009).

At 4 months of age, infants showed enhanced alpha desynchronization in the object-directed compared to the object-averted condition. Alpha desynchronization is a sensitive measure for attentional mechanisms that suppress irrelevant information and therefore focus attention on relevant information (Ward, 2003). Social cues such as eye gaze or head turn can guide infants' attention and can lead to enhanced memory encoding of cued objects in 4-month-olds (Hoehl, Wahl, et al., 2014; Hood, Willen, & Driver, 1998; Reid & Striano, 2005; Reid et al., 2004; Wahl et al., 2013). Thus, alpha desynchronization in the object-directed condition may reflect focused attention to gaze cued objects and thereby be related to social learning processes (Hoehl, Michel, et al., 2014).

At the same age, no difference between conditions was found in the theta range. So far, studies that have related theta synchronization to attentional processes have all investigated slightly older infants (Bazhenova et al., 2007; Orekhova et al., 1999; Orekhova et al., 2006; Stroganova et al., 1998). Theta synchronization has nonetheless been discussed to be related to the involvement of an attention network that is responsible for an executive control of attention that emerges between 4 and 6 months of age (Bazhenova et al., 2007; Mundy & Newell, 2007; Orekhova et al., 1999). As attention is thought to be guided automatically by social cues at four months, it is possible that this attention network is not yet involved in processing social cues in our sample.

Similarly to the 4-month-old infants, 9-month-olds also showed enhanced alpha desynchronization in the object-directed condition but their theta activity did not differ between conditions. At that age, infants are able to use joint attention interactions for enhanced object processing (Cleveland et al., 2007; Striano, Reid, & Hoehl, 2006) and alpha desynchronization has been observed in joint attention interactions (Hoehl, Michel, et al., 2014). As in the 4-month-olds, eye gaze direction in the object-directed condition may guide infants' attention to a relevant object, thus attention is focused on that object and alpha desynchronization could reflect these processes. In comparison to the younger age group, 9-month-olds are increasingly able to monitor their own and another person's attention (Mundy & Newell, 2007). This additional skill improves the infant's ability to detect and analyze the looker-object relationship and thereby to differentiate between object-directed and object-averted eye gaze. However, even in this older age group, it is likely that automatic shifts of attention are still part of gaze cueing effects as it is known that they still exist in typically developing children and in adults (Friesen, Ristic, & Kingstone, 2004; Senju, Tojo, Dairoku, & Hasegawa, 2004). Alpha desynchronization during infancy could potentially relate to social object learning guided by the mechanisms that are present at each specific age: automatic cueing of attention in 4-month-olds and, additionally, more volitionally controlled shifts of attention at 9 months of age. It is worth highlighting that in 4- and 9-month-olds alpha desynchronized when compared to baseline in both conditions. This might be due to both conditions conveying information about an object-looker relation, but it is only in the object-directed condition that eye gaze direction and object location match. This matching enables the infant to relate another person's eye gaze to the object, which may lead to a focusing of attention on this stimulus. This, in turn might trigger processes similar to those found in adults in situations with mutual attentiveness (Lachat et al., 2012), that are reflected in enhanced alpha desynchronization. No difference in theta activity was found in the 9-

month-olds. As joint attention skills are better developed at that age and the attention network matures, we assume that infants can easily detect differences between conditions without or with less effort of an internal control of attention (Orekhova et al., 1999).

Whereas 4- and 9-month olds show no difference in theta activity but exhibit an enhanced alpha desynchronization, 5-month-olds show the reversed pattern: theta activity differed between conditions with enhanced theta synchronization in response to object-averted eye gaze, but alpha-band activity did not.

Why do the 5-month-olds differ in their response from the 4- and 9-month olds? The attention network, being related to theta synchronization, is assumed to develop precisely at that age (Mundy & Newell, 2007). Furthermore, at the same age, gaze following abilities and joint attention skills improve but are not yet fully developed (Gredebäck et al., 2010; Striano & Bertin, 2005). Moreover, the ability to use a joint attention context to learn about objects develops (Cleveland et al., 2007) and the reaction to social cues is changing from automatic shifts of attention to additional voluntary mechanisms. Five-month-old infants are just developing social abilities and might, therefore, be extremely sensitive to social cues and also to the disrupted relation between object and eye gaze in the object-averted condition. Thus, this condition may require more attentional control. In line with ERP results showing that only attentional processes and not memory processes are affected when a disturbed looker-object relation is presented to infants at that age (Hoehl et al., 2009), differences in theta activity but not in alpha were found in the current study.

Here, we investigated how processing of object-directed and object-averted eye gaze develops during infancy measuring oscillatory brain activity. While alpha desynchronization in 4- and 9-month-olds is probably reflecting focused attention that may enable early social learning processes, theta synchronization at 5 months may reflect the development of an executive attention network, and therefore, the transition from a rather automatic shift of attention in reaction to social cues to an enhanced deliberate control. The interplay between alpha- and theta-band activities represents striking developmental changes in infants' neural processing of social information. Future research is needed to investigate whether the differences in oscillatory brain activity are indeed related to the encoding or learning of new information.

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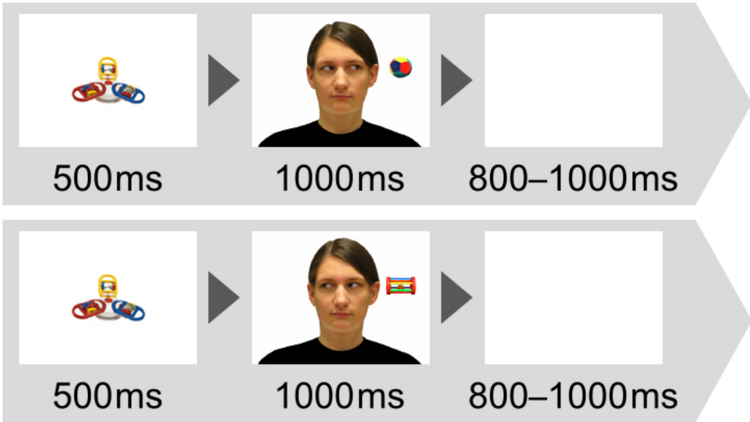

Figure 1. Examples of a trial in the object-directed condition (top) and the object-averted condition (bottom).

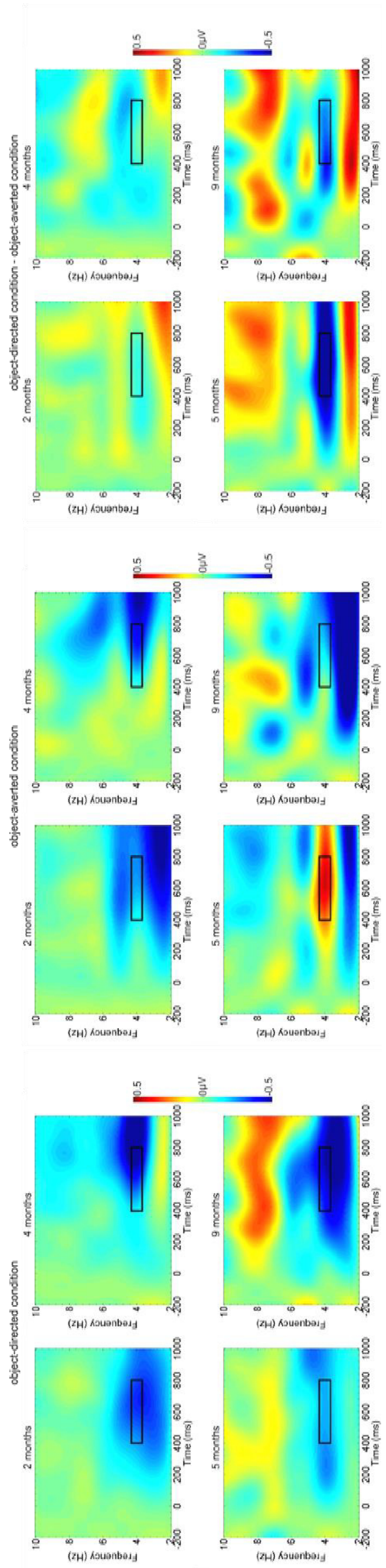

Figure 2. Mean time-frequency spectrum averaged across 5 fronto-central channels showing theta activity in the object-directed condition, the object-averted condition and the difference in theta activity between the object-directed – object-averted condition in 2-, 4-, 5- and 9-month-olds. The rectangle marks the analyzed time window at 4Hz.

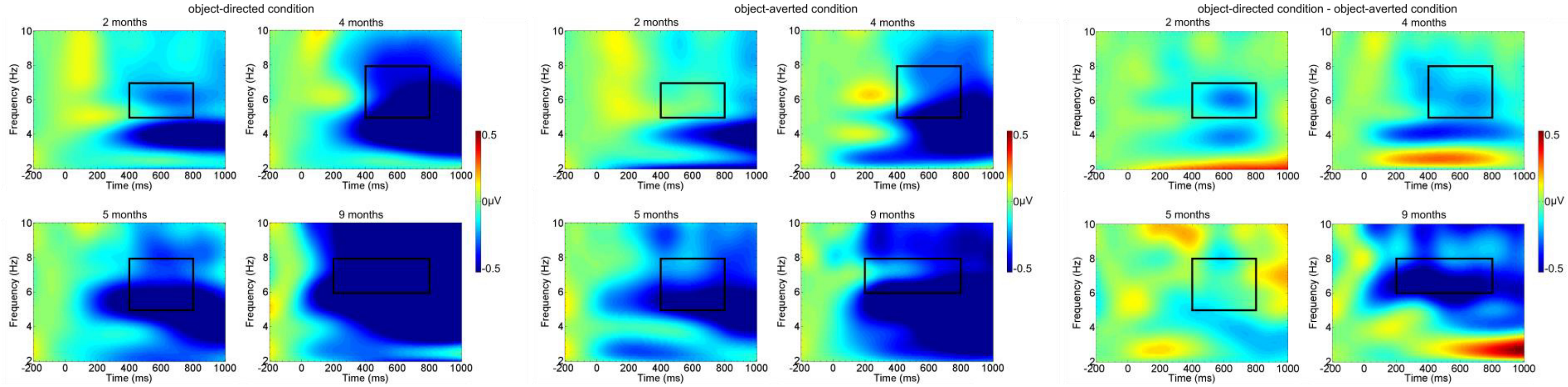

Figure 3. Mean time-frequency spectrum averaged across 5 posterior-occipital channels showing alpha activity in the object-directed condition, the object-averted condition and the difference in alpha activity between the object-directed – object-averted condition in 2-, 4-, 5- and 9-month-olds. The rectangle marks the analyzed time-frequency range.

Schrift II

This is the accepted manuscript of the article

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Effects of eye gaze cues provided by the caregiver compared to a stranger on infants' object processing

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Abstract

Previous research has shown that eye gaze affects infants' processing of novel objects. In the current study we address the question whether presenting a highly familiar face vs. a stranger enhances the effects of gaze cues on object processing in four-month-olds. Infants were presented pictures of the infant's caregiver and another infant's caregiver (stranger) either turning eye gaze toward an object next to the face or looking away from the object. Then objects were presented again without the face and event-related potentials (ERP) were recorded. An enhanced positive slow wave (PSW) was found for objects that were *not* cued by the caregiver's eye gaze, indicating that these objects required increased encoding compared to objects that were cued by the caregiver's gaze. When a stranger was presented, a PSW was observed in response to objects regardless of whether the objects were gaze-cued or not. Thus, the caregiver's eye gaze had a larger effect on infants' object processing than the stranger's gaze. This suggests that at four months of age the caregiver's eye gaze is easier to process for infants, more salient, or both. The findings are discussed in terms of early social cognitive development and face processing models.

Keywords: infants, event-related potentials (ERP), eye gaze, face processing, face familiarity

1. Introduction

Infants constantly encounter a large number of visual stimuli, familiar and novel objects and persons. Many questions remain concerning how preverbal infants structure their visual input, guide their attentional resources, and process novel stimuli. Recently it was shown that infants use cues of visual attention provided by adults when guiding their attention toward unfamiliar objects (Cleveland et al., 2007; Cleveland & Striano, 2007; Hoehl et al., 2008; Parise et al., 2008; Reid & Striano, 2005; Reid et al., 2004; Striano et al., 2006).

In a series of behavioral experiments Cleveland and colleagues investigated the effects of joint attention on infants' encoding of novel objects in a naturalistic setting with a live experimenter (Cleveland et al., 2007; Cleveland & Striano, 2007). Infants were familiarized with one object either in a triadic interaction, in which the adult alternated gaze between infant and object including phases of mutual gaze, or in a control condition, in which the adult did not engage in eye contact with the infant. In a subsequent test phase the familiarized object was presented together with a novel object and novelty preference scores were compared across conditions. Infants at 7 and 9 months of age showed a significantly larger novelty preference for the unfamiliar object if they had been familiarized with the first object in a triadic interaction compared to the control condition.

In a study by Reid and colleagues (2004) 4-month-old infants saw a face shifting eye gaze either toward or away from a small object presented next to the face. Objects were then presented again without the face and infants' brain responses (event-related potentials, ERP) to the objects were measured. Infants showed an increased positive slow wave (PSW) for objects that were *not* cued by the adult's eye gaze compared to objects that were cued by the adult's gaze. Amplitude of the PSW has been associated with updating the memory representation of a partially encoded stimulus (Nelson, 1994; Snyder, 2010). This suggests that in the study by Reid et al. (2004) objects that were not cued by the adult's eye gaze subsequently required increased processing compared to the cued objects, which were presumably more effectively encoded during the presentation with the face. This interpretation was later supported in a behavioral looking time study with 4-month-old infants (Reid & Striano, 2005). In this study a face shifted eye gaze toward one of two objects that were displayed on the right and left side of the face on a computer monitor. Then the objects were presented again without the face and infants' looking times for both objects were measured. Infants looked significantly more toward the non-cued compared to the cued object. This visual preference for the non-cued object was interpreted as a novelty preference due to the fact that non-cued objects were presumably less well encoded and consequently more novel to the infants compared to the cued objects. Twelve-month-olds also show a temporary visual preference for non-cued objects compared to cued objects in a similar paradigm (Theuring et al., 2007). These results suggest that others' eye gaze helps infants to direct attention toward relevant objects, thereby facilitating memory encoding of the gaze-cued objects.

Based on these empirical findings the Directed Attention Model (DAM) of infant social-cognitive performance was developed (Hoehl et al., 2009; Reid & Striano, 2007). This information processing model describes the perceptual stages of processing social information which are required in order to respond appropriately to a social partner. The stages of this model involve the detection of a social agent (1), the identification of the social agent (2), the detection of the other's attention focus in relation to oneself (3), and the detection of the other's attention focus in relation to other objects or persons (4). According to this model the detection of another person's attention focus should be facilitated if the person is familiar to the observer because identification of a highly familiar face should be facilitated relative to a strange face and this should affect the subsequent processing stages. Though there is evidence that familiarity of a face enhances gaze cueing effects in female adults (Deaner et al., 2007), this assumption has not been tested empirically with infants.

Six-month-olds respond with an increased Negative central (Nc) component to presentations of their mother's face compared to a dissimilar looking stranger's face, indicating that infants recognize their mother's face and presumably direct increased attention toward their mother's face (de Haan & Nelson, 1997, 1999). There is behavioral evidence that infants discriminate their mother's face from other faces even few hours after birth (Bushnell et al., 1989). However, only a few studies have tested whether infants' processing of social cues provided by a face is affected by familiarity. For instance, 3.5-month-old infants' discrimination of dynamic emotional expressions in an intermodal matching task is enhanced when the infant's mother compared to a stranger is shown (Kahana-Kalman & Walker-Andrews, 2001; Montague & Walker-Andrews, 2002). However, to date no study has tested whether the effects of eye gaze cues on infants' object processing are affected by familiarity of the face.

In the current study 4-month-old infants are presented with pictures of their caregiver (mother or father) and a stranger (another infant's mother or father) turning eye gaze either toward or away from a small object presented on the right or left side of the face. Then the objects are presented again without the face. We predict that 4-month-old infants will show an increased PSW response for non-cued objects compared to cued objects because cued objects have been more effectively encoded and require relatively less processing when being presented again without the face. This effect is expected to be stronger for the caregiver's face compared to a stranger's face. In addition, we predict a larger Nc amplitude in response to the caregiver's face compared to a stranger's face because this effect has been observed in previous research with 6-month-old infants (de Haan & Nelson, 1997, 1999).

2. Materials and methods

2.1 Participants

All participating infants were born full term (37 - 41 weeks) and were in the normal range for birth weight. Sixteen infants were included in the final sample (8 females, age range: 4 months, 2 days to 4 months, 25 days; average age: 4 months and 13 days). Another 18 infants were tested but excluded from the sample because they failed to reach the minimum requirement of 10 artifact free trials per condition for averaging. This attrition rate can partly be accounted for by the relatively large number of four conditions tested within subjects, but it is within the typical attrition rate for infant ERP-studies of 50-75% (DeBoer et al., 2007). Two additional infants were excluded from the sample because their mothers were not photographed correctly prior to testing. Infants excluded from the final sample did not differ significantly from the included infants in terms of age (average age 4 months, 14 days) or sex ratio (8 females, 12 males; Mann-Whitney-U-test, $p < 0.3$). All experiments were conducted with the understanding and informed consent of each participant's parent. The procedures of the study were approved by the ethics committee of the Fakultät für Verhaltens- und Empirische Kulturwissenschaften, Heidelberg.

2.2 Stimuli

The infant's mother (or in one case the father) was photographed in front of a light grey background (see *Figure 1* for an example). Caregivers were asked to look friendly, but calm, with no overt smiling. Three pictures were taken: one picture with eye gaze directed to the front, one picture with eye gaze averted to the left and one picture with eye gaze averted to the right. Caregivers were instructed to look toward the camera for the direct gaze picture and toward pre-defined positions in the room for the left and right averted gaze pictures. Caregivers were also asked not to move their heads when switching eye gaze between photographs. If necessary, several pictures were taken and caregivers received feedback to minimize head movement. The parent's clothes were covered with a black cape. Each parent served as the familiar face for his or her own infant and as a stranger for another participant. A father who accompanied a participating mother also had his picture taken and was only presented as the strange face for the one infant who came with his father. Caregivers and strangers were only matched for glasses (if they indicated that their infant most frequently sees them wearing glasses) and were otherwise dissimilar looking. Caregivers were asked whether they knew the stranger chosen for their infant prior to testing to ensure that infants were not familiar with the strangers. Portrait pictures were then overlaid with small pictures of colorful toys that were displayed next to the faces either to the left or right side, at the height of the pupils of the face. A number of 80 different objects were presented. Each object was presented once in the cued condition and once in the non-cued condition resulting in a maximum of 160 trials. Each object was presented only once in each half of the stimulus presentation. Faces were presented at a width of approximately 18 cm (SD=2.8 cm, visual angle of 11.3°) and a height of 29 cm from head of hair to shoulder (SD=1 cm, visual angle of 17.8°). Objects alone were about 7 x 7 cm of size (visual angle of 4°) and were presented at a distance of about 3 cm (visual angle of 2°) from the face at the height of the eyes. Luminance of the objects as measured with GIMP 2.6 (mean of brightness values across the image ranging from 0-255) was on average 193 (SD = 25). All objects were abstract toys.

-Insert Figure 1 about here-

2.3 Procedure

Infants sat on their caregiver's lap in a dimly lit room, at a viewing distance of 90 cm away from a 70 Hz 19-inch stimulus monitor. The experiment consisted of one block with 160 trials (40 trials per condition: cued/caregiver, non-cued/caregiver, cued/stranger, non-cued/stranger). Stimuli were presented using the software Presentation (Neurobehavioral Systems, Albany, USA). The four conditions were presented to the infant in a random order with the constraints that the same gaze condition (cued/ non-cued) was not repeated more than 3 times consecutively and that the same familiarity condition (caregiver/ stranger) was not repeated more than 3 times consecutively. Furthermore, object location and eye gaze direction were repeated 3 times maximum. Because of an error in the initial program, these restrictions were only applied in the first 52 trials for one of the subjects. After trial 52 for this one subject the non-cued condition was shown up to 6 times in a row and after trial 74 up to 7 cued trials were presented consecutively. Re-running all statistical analyses without this one participant did not yield any different effects, thus the infant was included in the final sample. Each trial started with a centrally presented face with gaze directed to the front and a small colorful object on the left or right side next to the face (*Phase 1:* caregiver or stranger, presented for 1000 ms), followed by the same face with gaze directed to the left or right side either toward the object or away from the object (*Phase 2:* 1500 ms), resulting in an apparent movement of the eyes from the front to the side as used in previous research on gaze motion processing (Watanabe et al., 2006). The face, directing gaze either toward or away from the object, was followed by a brief blank screen period (400-600 ms), and then the object was presented alone in the centre of the screen (*Phase 3:* 1000 ms). Each trial was followed by a blank screen period, whose duration varied randomly between 600-800 ms. If the infant became fussy or uninterested in the stimuli, the experimenter gave the infant a short break. The session ended when the infant's attention could no longer be attracted to the screen. EEG was recorded continuously and the behavior of the infants was also video-recorded throughout the session.

2.4 EEG recording and analyses

EEG was recorded with a 32 channels ActiCap system (Brain Products, Gilching, Germany) containing active electrodes based on Ag/AgCl sensors, which were attached to an elastic cap and mounted according to scalp locations of the 10-20 system. Data were amplified via a BrainAmp amplifier. Data were referenced to the right mastoid and recorded with a sampling rate of 250 Hz. Horizontal and vertical electro-oculograms were recorded bipolarly. EEG data were re-referenced offline to the linked mastoids and a bandpass filter was applied from 0.3-30 Hz. Artifacts caused by eye and body movements were removed from the data before averaging. In a first step, a gradient criterion was used for a semi-automatic artifact rejection allowing a maximum voltage step per sampling point of 100 μV to eliminate large movement artifacts. In addition, data were scanned manually trial per trial in order to match infants' EEG data with the simultaneously video-recorded behavior and in order to detect small blinks and eye movements on EOG channels. Only trials were included in which the infant had looked to the screen during the whole trial (gaze to front, gaze to side, and object alone) and displayed no eye or body movements. ERPs were time-locked to the onset of the object alone (*Phase 3*). For additional analyses, ERPs were also averaged time-locked to the presentation of the face with gaze to the front and gaze to the side (*Phases 1 and 2*). Data were segmented into epochs from 200 ms before stimulus onset to 1500 ms after stimulus onset. A baseline correction was applied before averaging.

Each infant contributed 10 to 17 valid trials (mean of 12, SD 2) in the cued/caregiver condition, 10 to 19 valid trials (mean of 12, SD 3) in the non-cued/caregiver condition, 10 to 17 valid trials (mean of 11, SD 2) in the cued/stranger condition, and 10 to 16 valid trials (mean of 12, SD 2) in the non-cued/stranger condition.

3. Results

Grand average ERP responses for the cued and non-cued objects in the two familiarity conditions are presented in *Figure 2*. On frontal and central channels a large negative deflection was observed in the mid-latency range: the Nc component which is typically evoked by visual stimulation in infants and whose amplitude has been associated with the amount of attention allocated toward a stimulus (Richards, 2003). Visual inspection suggested that there might be an effect of gaze condition on this component, thus amplitude was analyzed in the Nc time-window (400-800 ms). The Nc was followed by a positive slow wave response (PSW), which was particularly pronounced in the non-cued/caregiver condition and in the stranger conditions while waveforms returned to baseline following the Nc in the cued/caregiver condition. Amplitude of this slow wave was analyzed in a later time-window (1000-1500 ms). Greenhouse-Geisser corrections were employed where applicable in all reported statistical tests and level of significance was set at $p < 0.05$.

3.1 Negative central component

Mean amplitude between 400-800 ms after stimulus onset was taken as dependent variable in a repeated measures analysis of variance in order to assess differences in amplitude across conditions for the Nc. Within-subjects factors were familiarity (caregiver/stranger), gaze (cued/non-cued), and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4). No significant main effects or interactions were found, all *p*s > 0.1. No effects were found when peak amplitude of the Nc was used for analysis instead of mean amplitude, all *p*s > 0.1. See *Table 1* for means and standard deviations of Nc amplitude for all conditions.

3.2 Positive Slow Wave

Mean amplitude was assessed in a time window between 1000-1500 ms after stimulus onset. The same statistical analyses were carried out as for the Nc. A significant main effect of gaze condition was found for amplitude of the PSW, $F(1,15) = 5.24$, $p = 0.037$, $\eta_p^2 = 0.259$. Mean PSW amplitude was increased for objects in the non-cued condition (mean = 11.32 μV, SE = 2.8) compared to objects in the cued condition (mean = 4.45, SE = 3.3). There was also an interaction between familiarity and gaze condition, $F(1,15) = 5.38$, $p = 0.035$, $\eta_p^2 = 0.264$. See *Table 1* for means and standard deviations of PSW amplitude for all conditions.

When amplitude of the PSW was analyzed for the caregiver's face condition only, there was a highly significant main effect of gaze, $F(1,15) = 17.5$, $p = 0.001$, $\eta_p^2 = 0.539$. Amplitude was larger for the non-cued objects (mean = 15.66 μV, SE = 3.1) compared to the cued objects (mean = -0.81 μV, SE = 3.5). When amplitude of the PSW was analyzed for the unfamiliar faces only, no main effect of gaze condition was found, $F(1,15) = 0.2$, $p = 0.657$,

η_p^2 = 0.013, and no interaction of electrode by gaze condition was found, $F(9,7) = 0.87$, p = 0.49, η_p^2 = 0.055. This suggests that gaze condition only had an effect on infants' object processing when their caregiver's face was presented.

When amplitude of the PSW was analyzed only for the cued objects, there was a significant main effect of familiarity, $F(1,15) = 6.59$, p = 0.021, η_p^2 = 0.305. Amplitude was larger for objects cued by the stranger (mean = 9.73 μV, SE = 4.2) compared to objects cued by the caregiver (mean = -0.81 μV, SE = 3.5). There was also a significant interaction of familiarity by electrode, $F(1,15) = 6.1$, p = 0.013, η_p^2 = 0.887. Subsequent t-tests contrasting amplitudes of both familiarity conditions for each electrode separately revealed that significant differences were found on FC1, FC6, and Cz, ps < 0.05 (two-tailed). Marginally significant differences were also observed on F3 and FC5, ps < 0.1 (two-tailed). On each of these channels amplitude was larger for cued objects in the stranger condition compared to cued objects in the caregiver condition suggesting that objects cued by the caregiver required less memory updating when being presented again compared to objects cued by a stranger which elicited a strong PSW response. When amplitude of the PSW was analyzed for the non-cued objects only, no main effect for familiarity condition was found $F(1,15) = 1.92$, p = 0.186, η_p^2 = 0.113, and no interaction of electrode by familiarity condition was found, $F(9,7)$ = 1.1, p = 0.481, η_p^2 = 0.577, suggesting that non-cued objects were processed similarly in both familiarity conditions.

-Insert Figure 2 and Table 1 about here-

3.3 ERP responses to the faces

The PSW analyses showed significant differences in infants' responses to the cued objects between both familiarity conditions. In order to examine whether caregivers' and strangers' faces were processed differently *per se* we also analyzed infants' responses to the caregivers vs. strangers looking toward the front with the object next to the face (*Phase 1* of each trial). In particular, an effect on the Nc component is conceivable as increased Nc amplitude was found for the mother's face compared to a stranger's face in previous research with 6-month-olds (de Haan & Nelson, 1997, 1999). Therefore, a repeated measures analysis was run with mean amplitude in the Nc time-window (400-800 ms) as dependent measure. Within-subjects factors were familiarity (caregiver/stranger) and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4). Gaze was not included as an independent factor because in *Phase 1* trials did not yet vary depending on the gaze condition. No main effect for familiarity condition, $F(1,15) = 0.96$, $p = 0.343$, $\eta_p^2 = 0.06$, and no interaction of electrode by familiarity condition was found, $F(9,7) = 1.02$, $p = 0.408$, $\eta_p^2 = 0.064$. Amplitude was similar for the caregivers' faces (mean = -14.4 μV, SE = 2.8) and the strangers' faces (mean = -17.8 μV, SE = 3.5).

We also analyzed ERP responses to faces looking to the side, either toward or away from the object (*Phase 2* of each trial). No distinct positive or negative deflection was observed in response to stimuli in *Phase 2* of the trial presentation. This is likely because there was no pause between faces looking toward the front and faces with eye gaze directed to the side. The lack of a blank screen before stimulus onset and the immediate repetition of almost identical face stimuli likely caused a suppression of ERP responses. For statistical analyses we thus chose a larger time-window based on visual inspection in which slight amplitude differences between conditions were observed across fronto-central channels: 300-1000 ms. A repeated measures analysis of variance was run on mean amplitude with familiarity (caregiver/stranger), gaze (cued/non-cued), and electrode (F3, Fz, F4, FC1, FC2, FC5, FC6, C3, Cz, C4) as within-subjects factors. There was no significant main effect of familiarity condition, $F(1,15) = 2.67$, p = 0.123, $\eta_p^2 = 0.151$, no interaction of familiarity by gaze condition, $F(1,15) = 2.86$, p = 0.112, $\eta_p^2 = 0.16$, and no other significant main effects or interactions, all *p*s < 0.2.

4. Discussion

We addressed the question whether eye gaze cues of a familiar face have stronger effects on 4-month-old infants' object processing compared to a stranger's gaze. As predicted, we found an increased PSW response for objects that were *not* cued by the caregiver's eye gaze compared to objects that were previously gaze-cued. No effect was found for the unfamiliar faces. Our results summarized in *Table 1 and Figure 2* reveal that only objects cued by the caregiver elicited a return of the ERP response to baseline almost immediately following the Nc. When responses to cued objects were contrasted directly for both familiarity conditions, cued objects in the stranger condition elicited a significantly larger PSW response compared to objects cued by the caregiver. This indicates that objects cued by the caregiver required less memory updating compared to objects cued by a stranger because PSW amplitude has been associated with memory encoding in previous research (Nelson, 1994; Nelson & Collins, 1992; Snyder, 2010). The non-cued objects, in contrast, required more elaborate processing, regardless of the familiarity condition, as evidenced by a large PSW for non-cued objects in the caregiver condition and in the stranger condition.

In the unfamiliar face condition infants showed an Nc and subsequent PSW that did not differ in amplitude between the cued and non-cued objects. This lack of an effect of eye gaze was unexpected, since in the original study by Reid and colleagues (2004) only strange faces were shown to the infants. Nonetheless, the authors found an increased PSW for non-cued objects similar to the effect we found it in the familiar face condition. Procedural differences between our study and the original study may have impeded the effect of gaze cues in the strange face condition in the current experiment. First, we used an apparent motion paradigm subsequently presenting a face with direct gaze and the same face with averted gaze because static pictures were easier to control and to produce with the participating mothers and fathers in the lab prior to testing compared to filmed clips. Reid et al. (2004), in contrast, showed filmed footage of eye movement, which presumably produced more natural gaze shifts. Furthermore, each infant in the current study received a different pair of faces, which may have introduced additional variance compared to the original study. Finally, four conditions were tested within-subjects compared to only two conditions in the original study, resulting in a smaller number of available trials per condition (in the study by Reid et al., 2004, infants contributed a minimum number of 15 trials per condition).

Infants showed no difference in the PSW response for cued and non-cued objects in the strange face condition. However, a strong effect was found in the familiar face condition: Infants responded with an increased PSW to non-cued objects compared to objects previously cued by their caregiver's eye gaze. Responses to objects that were gaze-cued by the caregiver returned to baseline following the Nc indicating that these objects were fully encoded. This finding supports the view that eye gaze facilitates young infants' object processing by directing infants' attention to gaze-cued stimuli. Why does the caregiver's face in particular have this effect? In the following we discuss several factors that might have made the caregiver's eye gaze particularly salient for the infant and/or easier to process when compared to the stranger's gaze:

(1) Increased attention was directed to the caregiver's face.
(2) Processing of the caregiver's face and eye gaze was facilitated because of increased perceptual familiarity.
(3) Processing of the caregiver's eye gaze was facilitated or enhanced because of personal familiarity and previous interactions.

These possibilities are not mutually exclusive. It might well be that several factors worked in combination rendering the caregiver's eye gaze cues more effective than the stranger's cues in the current study.

First, differences in attention between conditions should be considered. It is conceivable that infants paid more attention to the caregiver's face compared to a strange face because the caregiver's face is a highly salient stimulus for young infants and because seeing the caregiver's face on a screen may be particularly unusual. In previous research 6-month-old infants responded with an enhanced Nc response to their mother's face compared to a stranger's face which may be interpreted as reflecting the allocation of more attention toward the mother's face (de Haan & Nelson, 1997, 1999). To test for a similar effect in the current study we also analyzed infants' Nc responses time-locked to the onset of the faces looking toward the front at the beginning of the trial. Infants showed no differences in Nc amplitude for their caregiver's face compared to the stranger's face. No differences in ERP responses were found for the faces looking to the side either. Thus, although infants apparently distinguished between their caregiver and the stranger this was not reflected in their ERP responses to the faces themselves. A different paradigm was used than in the studies by de Haan and Nelson (1997, 1999) and younger infants were tested which may explain the lack of a familiarity effect for the Nc. Though we cannot rule out that attention played a role in the current study, we found no evidence that infants directed more attention to stimuli in the familiar face condition *per se.* An interpretation of the PSW effect for non-cued vs. cued objects in the familiar face condition solely based on attention thus seems unlikely. However, there may have been differences in infants' processing of the caregiver's face compared to the stranger's face that cannot be captured by recording ERPs, e.g. activation in subcortical pathways involved in face and emotion processing (Johnson, 2005).

Apart from attention differences between conditions other functional mechanisms are conceivable. One possibility is that a highly familiar face is easier to "decode" for infants enabling a more efficient use of social cues like eye gaze direction as proposed by the DAM (Hoehl et al., 2009; Reid & Striano, 2007). According to the DAM, a social agent is first detected based on salient perceptual features like the presence of eyes and/or biological motion. This obligatory processing step should not differ as a function of personal familiarity.

In a second step the agent is identified, e.g. based on individual facial characteristics. This processing step was probably facilitated in the caregiver condition because of the perceptual familiarity of the caregiver's face. Possibly, rapid identification of the caregiver's face enhanced and/or sped up the subsequent processing stages, namely detection of the other person's attention focus in relation to the self (eye contact in *Phase 1* of each trial) and in relation to something in the environment (i.e. cued vs. non-cued objects in *Phase 2* of each trial). In contrast, facial identity processing may have been more difficult in the stranger condition. Consequently, infants were only able to use the very subtle eye gaze cues provided by the caregiver, which could not be processed in the stranger condition in the current study. In fact, contrasting a highly familiar face with a complete stranger may have accentuated the influence of processing stage 2 of the DAM in the current experiment because infants may have been particularly engaged in comparing the stranger's face to their caregiver's face, thus neglecting the stranger's eye gaze cues in relation to the objects.

In the classic face processing model by Bruce and Young face recognition was separated from analyses of facial expressions and speech movement analysis (Bruce & Young, 1986). Subsequent accounts on face processing have also stressed the cognitive and anatomical dissociation between facial identity recognition and the perception of changeable aspects of a face such as emotional expression and eye gaze, although interactions between those functions were not ruled out *per se* (Haxby et al., 2000). This view is supported, for instance, by evidence that familiarity with a face does not affect the judgement of facial expressions in healthy adults (Bruce, 1986). It should be noted, however, that infants' discrimination of emotional expressions in an intermodal matching task is enhanced when a highly familiar face (i.e. the infant's mother) is presented compared an unfamiliar face (stranger), or a relatively less familiar face (the infant's father when the mother is the primary caregiver, see Montague & Walker-Andrews, 2002). More recently it has been suggested that instead of completely distinct pathways for processing facial identity and communicative social cues a multidimensional system may process both kinds of information with parts of this system being relatively more involved in the analysis of facial identity than in analyses of social cues and *vice versa,* allowing for mutual influences of different kinds of information provided by a face (Calder & Young, 2005). Interestingly, at least in adult females effects of gaze cueing are enhanced for personally familiar faces relative to unfamiliar faces (Deaner et al., 2007). The current study is the first to show enhanced effects of gaze cues on object processing for familiar faces compared to unfamiliar faces in infants. Our finding is in line with the suggestion that a familiar face may be easier to identify by an infant, consequently facilitating the processing of attentional cues provided by the face as proposed by the DAM (Hoehl et al., 2009; Reid & Striano, 2007).

In the current study faces of caregivers were contrasted with completely unfamiliar faces. Thus, we cannot rule out that aspects relating to the relationship between caregiver and infant, e.g. quality of attachment, rather than purely visual experience with the face can account for the observed effects. It is possible that infants were primarily occupied with processing the information conveyed by their caregiver's eye gaze in the current experiment, thus neglecting the information provided by the stranger. In fact, infants may have been "picking out" the objects cued by the caregiver. Consequently, objects in the strange face condition were less well encoded and elicited a PSW regardless of the stranger's gaze direction. In a between-subject design presenting only strangers to one group of infants we would predict the same pattern of results as found by Reid et al. (2004).

Even in adults greater gaze cueing effects have been found for personally familiar faces (Deaner et al., 2007), whereas it does not make a difference whether the same previously unfamiliar face is presented throughout hundreds of trials compared to a different face being shown in every trial of a gaze cueing experiment (Frischen & Tipper, 2004). It is possible that infants at four months of age have learned in numerous situations that their caregiver's eye gaze is informative and it might consequently bear a specific meaning for them. This interpretation, however, would hardly be consistent with the notion that gaze cueing effects in 4-month-olds and younger infants primarily reflect automatic attention shifts (Hoehl et al., 2009). Future studies should manipulate face familiarity in order to directly test how much visual experience with a face (with or without face-to-face interaction) is necessary for infants to be able to use an adult's gaze cues in the current paradigm.

Future studies may also consider developmental changes in infants' responding to and interacting with their caregivers as compared to strangers. For instance, whereas 6-month-olds show an increased Nc to pictures of their mother compared to a stranger (de Haan & Nelson, 1997), the opposite response pattern is found in 3- to 4-year-old children (Dawson et al., 2002). When faced with an ambiguous toy infants at 12 months of age prefer to look at a strange experimenter compared to their mother and regulate their behavior in accordance with the experimenter's emotional cues (Stenberg & Hagekull, 2007). In a free play situation infants at 7 and 9 months of age coordinate attention toward a toy more frequently with a stranger compared to their mother (Striano & Bertin, 2005). A recent longitudinal study using eye tracking showed that a "stranger preference" in terms of following gaze shifts to objects occurs between 4 and 6 months of age (Gredeback et al., 2010). Taken together, these findings suggest that infants older than those tested in the current study may in fact be more inclined to interact with and gain information from strangers compared to their caregivers in experimental contexts.

To conclude, 4-month-old infants' processing of novel objects is facilitated by an adult's gaze cues, especially if the infant's caregiver is presented. The caregiver's eye gaze may be particularly salient and/or easier to process for young infants. Our results suggest that familiarity with a face enhances the processing of eye gaze cues in young infants. It remains to be examined in future research whether the personal relationship or purely perceptual familiarity is crucial for the effect.

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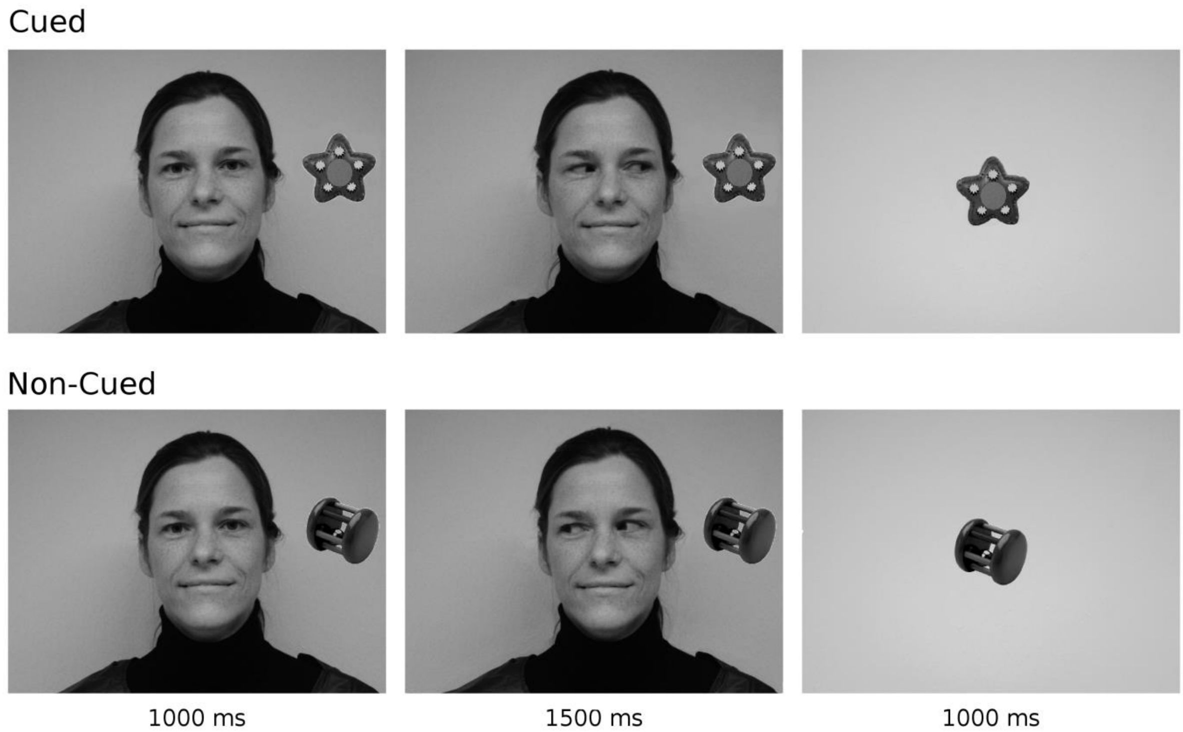

Figure 1. Stimuli. Example of a mother who was presented as the familiar face to her own infant and as a strange face to another infant. In half of the trials the object was cued by the person’s eye gaze and in half of the trials the object was non-cued. Gaze direction and object location were counterbalanced across trials.

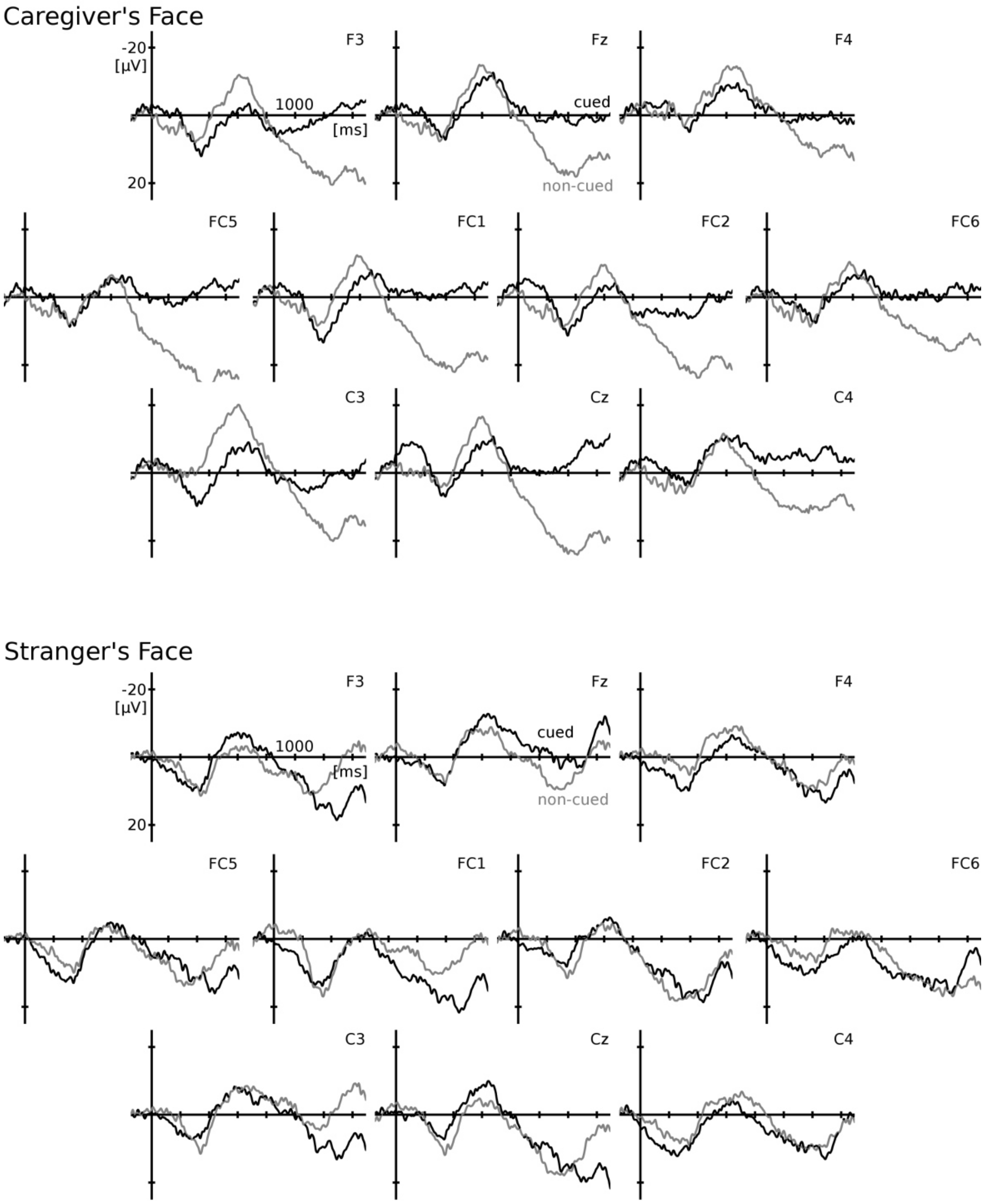

Figure 2. ERP results. Grand average ERP responses for the familiar face condition (upper panel) and the unfamiliar face condition (lower panel). When the caregiver's face was presented infants' responses returned to baseline after the Nc for cued objects (black line) while a large PSW response was found in response to non-cued objects (grey line). When a stranger's face was presented a PSW was found for cued objects and non-cued objects which did not differ in amplitude across conditions. Note that negative is plotted upwards.

Table 1. Mean PSW and Nc amplitude in μV *(PSW: 1000-1500 ms; Nc: 400-800 ms on frontal and central channels) and standard deviations (in parentheses) in response to the objects.*

	PSW		**Nc**	
	Cued	Non-cued	Cued	Non-cued
Caregiver	-0.81 (14.1)	15.66 (12.3)	-3.76 (11.2)	-6.67 (14.9)
Stranger	9.73 (16.9)	6.99 (20.3)	-2.28 (14.4)	-2.28 (15.7)

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The Influence of Familiarity on Explicit Eye Gaze Judgment in Preschoolers

Running head: Familiarity and explicit gaze judgment

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Abstract

The current study explores the influence of familiarity on explicit eye gaze judgment in preschoolers. We introduce reaction times for touches as a new measure for children studies. 4-to-6-year-old children saw either their caregiver's face or a stranger's face looking at an object or away from it. Children were asked to touch the face that was looking at the object and reaction times to correct touches were measured. Children reacted faster to strangers' faces than to their caregivers' faces. This might indicate that preschoolers used the face of a stranger more effectively as a source of information about the environment and for this reason detected the eye gaze-object-relationship faster. In addition, children's reactions were faster in a nonsocial shape-matching task than in the social eye gaze judgment task. The applied paradigm is appropriate to further investigate the development and influencing factors of explicit eye gaze judgments in preschoolers.

Keywords: Explicit eye gaze judgment, Preschoolers, Familiarity

The Influence of Familiarity on Explicit Eye Gaze Judgment in Preschoolers

Eye gaze is an important cue guiding attention and influencing the way humans perceive and process the environment already in infancy (see Frischen, Bayliss, & Tipper, 2007; Hoehl et al., 2009 for reviews on eye gaze processing in adults and infants). As parents play a crucial role for children, it is reasonable to assume that their eye gaze might be processed differently from eye gaze of strangers. Only few studies have investigated this question so far: On the behavioral level,infants at 6 months of age showed more gaze following in reaction to a stranger's face in contrast to the mother's face (Gredebäck, Fikke, & Melinder, 2010). In adults, familiarity facilitated eye gaze cueing only in women (Deaner, Shepherd, & Platt, 2007).

On the neurophysiological level, processing of familiar and unfamiliar faces was investigated in infants using event-related potentials (ERPs). An increased negative central component (Nc)) was found for the mother's face compared to a dissimilar looking stranger's face in 6-month-olds indicating that familiarity increases attention (de Haan & Nelson, 1997, 1999). In typically developed preschoolers the opposite effect was found: a decreased Nc was found in reaction to a photograph of the children's mother in comparison to a dissimilar stranger (Dawson et al., 2002). This suggests that early in development, caregivers receive increased attention from infants, whereas older children devote relatively more attention to strangers.

A recent study by Hoehl, Wahl, Michel and Striano (2012) did not find differences in processing familiar and unfamiliar faces in 4-month-olds. However, familiarity influenced object processing in infants: Infants saw pictures of either their caregiver's face or a dissimilar looking stranger's face looking towards an object or away from it. The object was then presented again without the face. Objects that were not cued by a familiar face elicited an enhanced positive slow wave (PSW) compared to objects cued by a familiar face. No cueing effects were found for the unfamiliar face. As the PSW is associated with updating memory representations of partially encoded stimuli (Snyder, 2010), the results suggest that objects cued by the caregiver were initially processed more deeply and needed less memory updating when presented again. The gaze of a highly familiar face acted as a more effective cue than a stranger's face facilitating object processing.

To our knowledge, no study has investigated the influence of familiarity on eye gaze processing in preschoolers yet. The current study aims to fill this gap.

There are currently two main paradigms to study eye gaze processing in preschoolers: (1) using implicit measures such as shifts of attention and (2) explicitly asking children to judge eye gaze directions. In studies following the first approach, children, similar to adults, reacted faster to targets appearing in gaze-cued locations compared to targets whose location was not previously cued by eye gaze (Ristic, Friesen, & Kingstone, 2002; Senju, Tojo, Dairoku, & Hasegawa, 2004).

A series of studies followed the second approach (see Doherty, 2006 for a summary on eye gaze judment literature in children). In the classic paradigm by Masangkay (1974) a person is surrounded by several objects and the child has to name or point to the object that the person is looking at. Assuming that children's attention is automatically oriented in the direction of the person's gaze, simply naming the object that automatically becomes their new focus of attention leads children to correct answers. Thus, explicit judgment and automatic orienting are confounded in this task. To disentangle both mechanism, Doherty, Anderson, and Howieson (2009) developed the looking-at-the-ball task. Here, the child sees two faces and one object (a ball). The child is asked ‘‘Which one is looking at the ball?”. The correct answer does not refer to the gaze-cued object, but the gaze itself. Only a minority of 2-year-old children solved the task, whereas at 3 years of age half of the children succeeded and almost all 4-year-olds passed it. Interestingly, the performance of children in this task was significantly correlated with the age of the participants, suggesting that abilities to solve this task develop between 2 and 4 years of age.

To succeed in this task, children do not only have to follow the eye gaze of two persons instead of one, they also have to judge the relation between two persons and an object. As this task is more complex and better suited to study explicit judgment of eye gaze direction than the classic one, we adapted it to take familiarity into account. In the current study, as in Doherty et al. (2009), children had to choose which one out of two photographed faces was looking at a shape in their middle. However, several changes were made in comparison to the original looking-at-the-ball task:

First, in Doherty et al. (2009) both faces presented in one trial did not only differ in their eye gaze direction, but different people were shown. It cannot be ruled out that perceptual differences between the two photos influenced results. We therefore showed two identical photographs in each trial, only one of whom was looking at the shape and the other one was looking away. Even though seeing two identical faces at the same time might be an unusual situation, this appears in both conditions (familiar and unfamiliar, see below) and should not lead to differences between conditions. Second, children in the current study were 4-to-6-years old and therefore older than in Doherty et al. (2009) and expected to be able to solve the task. This allows us to change the dependent variable from simple right/wrong distinctions to reaction times for correct decisions. Finally, only in half of the trials did children see the face of a stranger, in the other half they saw the face of one of their caregivers. This permitted us to measure the influence of familiarity on explicit eye gaze direction judgment.

As no other study, to our knowledge, has compared reaction times to caregivers' and strangers' gaze in this age group before, our hypotheses are tentative and can only be based on rather contradictory findings in infants and adults. If gaze following is facilitated for familiar faces in children as it is in female adults (Deaner et al., 2007) children should be faster to react if a familiar face serves as the stimulus. However, infants by six months of age showed more gaze following and by 7 and 9 months of age showed more coordinated attention with strangers than with their mothers (Gredebäck et al., 2010; Striano & Bertin, 2005), and at 12-to-24 months of age, they were seeking more information from strangers than from mothers in an ambiguous situation (Walden & Kim, 2005). If children at this age are more interested in information conveyed by a stranger than by the caregiver in an experimental setup, children should be faster in correctly judging the eye gaze direction of strangers than the eye gaze direction of mothers.

Method

Participants

16 children (10 female) in an age range of 4 years 2 months to 6 years 9 months (M = 5 years 6 months) participated in the study. Another 10 children were tested but excluded from the final sample due to experimenter error (n = 5) or failure to reach the inclusion criterion of responding correctly to three trials in a row in the second part of the study (n = 5). Parents were informed about the procedure and written consent of the parents was collected for each subject. The children received stickers as a reward. The study consisted of three parts; each part consisted of eight trials. On average children responded correctly to all 8 trials in part 1, 7.8 trials in part 2 (taken together, all included participants made 3 mistakes) and 7.3 trials in part 3 (taken together, all included participants made 11 mistakes). The study was approved by the Hunter College Human Research Protection Program of the Institutional Review Board.

Stimuli

The study consisted of three parts: (1) easy touching task, (2) shape-matching task and (3) eye gaze judgment task. The stimuli of all three parts were printed on papers sized 21 cm x 29.7 cm and basted into a binder which could be set up so that pages could easily be flipped. Each trial was separated by a blank page. For part 1, a trial consisted of the outline of a single shape in the center of the page. The shape was either a rectangle, a circle, a triangle or a square with maximal dimensions of 8.6 cm x 8.6 cm (see Figure 1a for an example). For part two, each trial consisted of two outlines of shapes at the left and right side and one shape filled with grey in the middle. All three shapes were equally distributed on the paper, so that the distance between shapes was about 2 - 3 cm (see Figure 1b for an example). For part 2, the same shapes as in part 1 were used. The stimuli of part 3 consisted of a circle filled with grey (4.8 cm x 4.8 cm) in the center of the page and two identical gray scale photos, one to the left and one to the right side of the circle. The size of the circle was 4.8 cm x 4.8 cm. The maximal expansion of the photos was 5.2 cm x 6.3 cm. The photos showed the shoulders and the face of either the participant's caregiver or a stranger with eye gaze to the left or the right side. Consequently, one face looked towards the circle and the other one looked away from it (see Figure 1c for an example). (Figure 1 about here)

Pictures of the caregivers were taken in advance and matched with a caregiver of another participant based on sex, hairstyle and ethnicity. Thus, the paired faces were somewhat similar to each other which was done to avoid effects due to overall visual differences between both faces. Presenting similar faces allows us to test the influence of familiarity more strictly than using dissimilar looking pairs. Studies with school children show that they can nearly perfectly recognize familiar faces on photographs and can tell whether they know a person or not (Boucher, Lewis, & Collis, 1998; Wilson, Pascalis, & Blades, 2007). We therefore assume that preschoolers recognize their caregivers on photographs. Parents were advised to show neutral facial expression on the photo. The pictures were edited in Adobe Photoshop® (v. 9.0.2) to gray scale and the outline of face and body was cropped, so that the background was removed.

Procedure

Testing took place in quiet areas generally at children's homes. The child was placed in arm distance from the binder. The distance between the binder and the child was held constant throughout testing. Each trial started with flipping the page of the binder, hence a new stimulus appeared.

Before every trial, the child was asked to put his hands on the hand-shaped outlines shown on a template on the table. This ensured that the kid's hands were on the table and in the correct distance to the binder when a trial started.

The study consisted of three parts which went on identically: Each part started with instructions given to the child. Before the beginning of every trial, the experimenter confirmed that the kid's hands where placed on the template and the kid was attentively looking to the binder. If not, the child was corrected and asked "Are you ready?" to ensure that the kid's attention was on the binder. A trial started only if those preconditions were fulfilled. The experimenter then repeated instructions in short single-sentence version and flipped the page so that the stimulus was visible to the child. The child answered with a touch on the binder. The experimenter then flipped the page again and a blank page appeared. If the kid answered correctly, the experimenter praised the kid verbally and went on with the next trial. The reaction of the experimenter to wrong answers differed between parts. See detailed descriptions for each part below. Each part consisted of 8 trials. After each part, the experimenter told the child that they will now play another game.

In part 1, the child had to touch a shape that was printed in the middle of a page. The shape was either a triangle, a circle, a rectangle or a square. Every shape appeared twice in part 1 and no shape was shown twice in a row. In this part, the child got familiar with the testing situation and the procedure (e.g. putting their hands on the template and touching as an answer). The instructions at the beginning of part 1 were as follows: “When I flip the page, you will see a shape – a square, circle, rectangle, or triangle. And all you have to do is touch the shape.” Immediately before every trial, the instructions were repeated as “Touch the shape”. If the kid did not touch the shape, the experimenter repeated the instructions.

Part 2 was a shape-matching task that was already used in other studies as a control condition for emotion matching (Herba, Landau, Russell, Ecker, & Phillips, 2006; Székely et al., 2011). The child was asked to touch the left or right shape that was the same as the one in the middle. In this part, the child got familiar with matching a peripheral stimulus with one in the middle and with choosing a correct answer by touching it. General instructions for part 2 were as follows: “You will now see three shapes and the shape in the middle will be filled in grey. All you have to do is touch the shape that looks like the grey one in the middle.” Immediately before each trial the instructions were repeated as: “Touch the shape that looks like the one in the middle”. The position of shapes was counterbalanced so that every shape appeared twice in the same position (left/right/middle). Additionally, in half of the trials the correct answer was to touch the left shape and in the other half of the trials the right shape so that no side bias could occur.

If the kid touched the wrong shape, the experimenter pointed to both shapes consecutively and asked for both shapes, if it looked like the one in the middle. If the kid still failed to touch the correct shape, the experimenter showed the child the correct shape and went on with the next trial. Only kids were included into the final sample that chose at least 3 trials correctly in a row in part 2. This ensured that children understood the paradigm and the task.

In part 3 the child had to touch the face that looked at the circle in the middle. General instructions for part 3 were as follows: “You will now see two faces. One of them is looking at a shape in the middle. All you have to do is touch the face that is looking at the shape in the middle.” Immediately before each trial, instructions were repeated as: “Touch the face that is looking at the shape in the middle.” Children did not know in advance that they will see a photograph of their caregiver. This way, a more spontaneous reaction to familiar and unfamiliar faces could be achieved. Mentioning the caregiver beforehand might have shifted children’s attention to the caregiver. This might have influenced the processing of the faces thus affecting the results.

Four different orders of trials were created and an equal number of four participants received the same order. Orders were counterbalanced so that the same eye gaze direction (left vs. right) and person (caregiver vs. stranger) were not repeated more than twice in a row. Additionally, two orders showed the caregiver in the first trial and two showed the stranger in the first trial. If the participant touched the wrong face, the experimenter pointed to both faces consecutively and asked for both faces, if it looked at the shape in the middle. If the kid still failed to touch the correct face, the experimenter showed the child the correct face and went on with the next trial.

Coding and Analyses

Mean reaction times for correct answers in each part were taken as the dependent variable. Time was measured doing a frame-by-frame analysis using QuickTime® Player 7.6.6 (Apple Inc., Cupertino, USA). Reaction times were measured as starting from the point when the page was flipped completely to the first touch of the sheet. Coding was done by two independent raters of whom one was blind to face familiarity in part 3, who agreed with a two-way random Intra-Class Correlation ICC= .97 on single trial level.

Results

A repeated measures ANOVA with the within-subject factor part (part 1 vs. part 2 vs. part 3) was conducted to assess differences between the three parts. Greenhouse-Geisser correction was employed and level of significance was set at $p < 0.05$. The main effect of part was highly significant, F (1.12, 16.77) = 54.824, $p < 0.001$, $\eta_p^2 = 0.785$, with reaction times in the first part being significantly faster (*M* = 517 ms, *SE* = 34 ms) than in the second part (*M* = 1314 ms, *SE* = 98 ms), and in the second part being significantly faster than in the third part (*M* = 2195 ms, *SE* = 224 ms).

Additionally, a paired t-test was conducted on mean reaction times for correct answers in part 3, comparing the reaction to the caregiver's face and the stranger's face in order to assess differences in reaction times due to familiarity. An equal number of familiar and unfamiliar trials were included into the analysis (t (15) = -0.613, $p = 0.55$). See table 1 for an overview of excluded and included trials. (Table 1 about here) Children were significantly faster in correctly selecting a stranger's face (*M* = 2010 ms, *SE* = 200 ms) looking at an object than in selecting their caregiver's face (*M* = 2364 ms, *SE* = 253 ms), t (15) = 2.44, p = 0.028 (see Figure 2). (Figure 2 about here)

Discussion

The current study investigated the influence of familiarity on explicit judgment of eye gaze direction in preschoolers. Children at age 4-to-6 years explicitly judged eye gaze direction of a stranger faster than eye gaze direction of their own caregiver. Additionally, children were faster in a nonsocial shape-matching task and even faster in an easy touching task than in the social eye gaze judgment task. As no explicit judgment was required in the easy touching task, this result is not surprising. This task was included to familiarize children with the testing situation and will therefore not be discussed further.

The current study adds several innovations to the existing literature on explicit eye gaze judgment.

First, we tested 4-to-6 year old children, which is slightly older than most of the existing literature on explicit eye gaze judgment (see Doherty et al., 2009; Riby & Doherty, 2009 for exceptions). It was therefore assumed that our subjects can already solve the task. Interestingly, the children that were excluded because they failed to reach the inclusion criterion of three correct answers in a row in part 2 (shape-matching task), were all younger than the average sample. However, no significant correlation was found between age and reaction times. It seems that older children can solve the task as they made very few errors. Their reaction times do not improve with age within the age range tested in the current study.

Second, we changed the dependent variable from a simple right/wrong distinction to reaction times. Additionally, children learned to use touching as selecting an answer. The existing literature with children either measured accuracy of touches (Székely et al., 2011) or reaction times to button presses (Herba et al., 2006). We combined those dependent variables in measuring reaction times of correct touches. As it was found that children reacted faster to unfamiliar than to familiar faces, the chosen measure seems to be discriminative for the given question. It emerged to be a well-working dependent variable for studies with children and can further be used for other research questions.

Third, in addition to an explicit judgment task using social stimuli, we added an explicit judgment task with nonsocial stimuli, the shape-matching task. The shape-matching task was used because it is an established task for children at this age or even younger (Herba et al., 2006; Székely et al., 2011). Children were significantly faster in reacting to the nonsocial than to the social stimuli. This is an interesting, yet not surprising finding. To solve the shape-matching task, children had to compare shapes at the side with the one in the middle. To solve the eye gaze judgment task, children had to pay attention to the eyes of each person. This may have been more difficult because the eyes were of smaller size than the shapes. Further studies may investigate explicit judgments to nonsocial stimuli using tasks that are more comparable with the social tasks. Using little arrows with a size comparable to eyes would be one example. Also, this would be in line with literature comparing implicit measures of eye gaze effects on attention with nonsocial cues like arrows (Ristic et al., 2002).

Finally, the existing literature on explicit judgment of eye gaze direction was extended by testing the influence of familiarity. To date, no study has investigated this question. We showed that children reacted faster to a stranger's face than to their caregiver's face. Several explanations may account for that. Children might have been confused about seeing their own caregiver on the photograph. Children were only told that they will see faces, but they did not know that some faces would be the ones of their caregivers. This enabled us to measure spontaneous reactions to the faces and not a verbally primed specific processing of their caregiver. It could be that children were distracted when seeing their caregivers because this was unexpected for them. However, only four children remarked verbally that they recognized their caregivers (e.g. "This is my mum.") when seeing them for the first time. When we removed the first trial per condition for these children, the effect did not change. This leads us to conclude that any initial surprise caused by seeing their caregiver on a photograph did not significantly alter the effect.

Another explanation is that familiar and unfamiliar faces are processed differently as it is the case in adults (see Natu & O'Toole, 2011 for a review on neural processing of familiar and unfamiliar faces). In infants there is no evidence on the neurophysiological level that mothers and strangers are processed with different speed as no effects on latency were found regarding familiarity using event-related potentials (de Haan & Nelson, 1997, 1999; Hoehl et al., 2012). However, an enhanced Nc was found in reaction to pictures of the mother in contrast to pictures of a dissimilar looking stranger in 6-month-olds (de Haan & Nelson, 1997, 1999). Furthermore, the gaze of a caregiver facilitates object processing more effectively than the gaze of a stranger in 4-month-olds (Hoehl et al., 2012). These studies suggest that infants allocate more attention to familiar than to unfamiliar faces and social signals such as eye gaze are more effective when coming from a familiar face. These neurophysiological results are somewhat contradictory to our results showing faster explicit judgment for the face of a stranger than the caregiver. Several explanations can account for this. The current study investigated much older children. In preschoolers, Dawson and colleagues (2002) showed that unfamiliar faces elicited an enhanced Nc. Thus they allocated more attention to unfamiliar compared to familiar faces. If unfamiliar faces were processed more attentively in the current study, the direction of their eye gaze consequently might have been detected faster. This could have led to faster judgments in reaction to unfamiliar faces, thus explaining our results.

Furthermore, the current study researches explicit eye gaze judgments and not object processing as it was done in the study by Hoehl and colleagues (2012). Children were not asked about characteristics of the shape in the middle but about the direction of eye gaze. Follow-up studies might test if the eye gaze of a familiar face influences the discrimination of cued objects more or less effectively than unfamiliar faces. Finally, the current study uses a behavioral paradigm. In the study of de Haan and Nelson (1997) infants only showed different reactions to familiar and unfamiliar faces on the neurophysiological but not on the behavioral level and it was stated that both measures represent different aspects of face processing. While ERPs inform about information processing itself, behavioral measures reflect the final state of this process. It is therefore worth to take a closer look at behavioral studies.

Our results are well in line with research showing that, on the behavioral level, infants process eye gaze of familiar and unfamiliar faces differently. They react with more gaze following to strangers by 6 months of age (Gredebäck et al., 2010) and show more coordinated attention with strangers than with mothers (Striano & Bertin, 2005) at 12-to-24 months of age. There is also evidence that children are seeking more information from strangers than from mothers in experimental settings. Already at 8 and 12 months of age, infants spent more time looking at strangers than at mothers in an imitation study (Devouche, 2004). In line with that, Walden and Kim (2005) found that 12-to-24-month-old infants looked more often to strangers in an ambiguous situation.

These studies suggest that children perceive strangers as an important source of information about the situation or environment in experimental setups. It might therefore be the case that children in the current study used the face of a stranger more effectively as a source of information about the environment and for this reason detected the eye gaze-object-relationship faster.

The current study expands and innovates an existing paradigm on explicit eye gaze judgment. The influence of familiarity on eye gaze direction judgments was investigated and results indicate that children at 4-to-6 years of age are faster in judging eye gaze direction of a stranger than of their caregivers. Adapting the looking-at-the-ball task of Doherty et al. (2009) and using reaction times for touches as the dependent variable, we hereby introduce a new measure that can also be used to investigate other questions. Measuring reaction times instead of simple right/wrong distinctions seems to be a promising approach to study eye gaze judgment and will lead to a better understanding of when and how children begin to judge eye gaze directions and which other factors (e.g. familiarity, emotional expressions) influence it.

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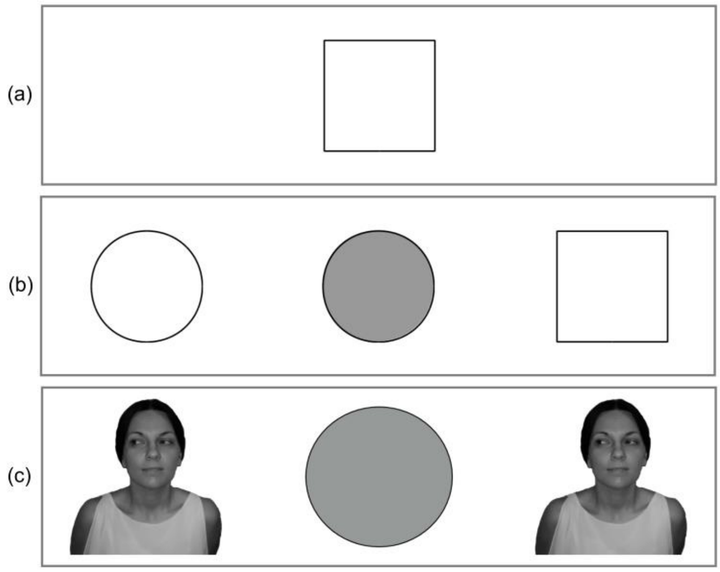

Figure 1. Example of trials of the simple touching task of part 1 (a), the shape-matching task of part 2 (b) and the eye gaze judgment task of part 3 (c).

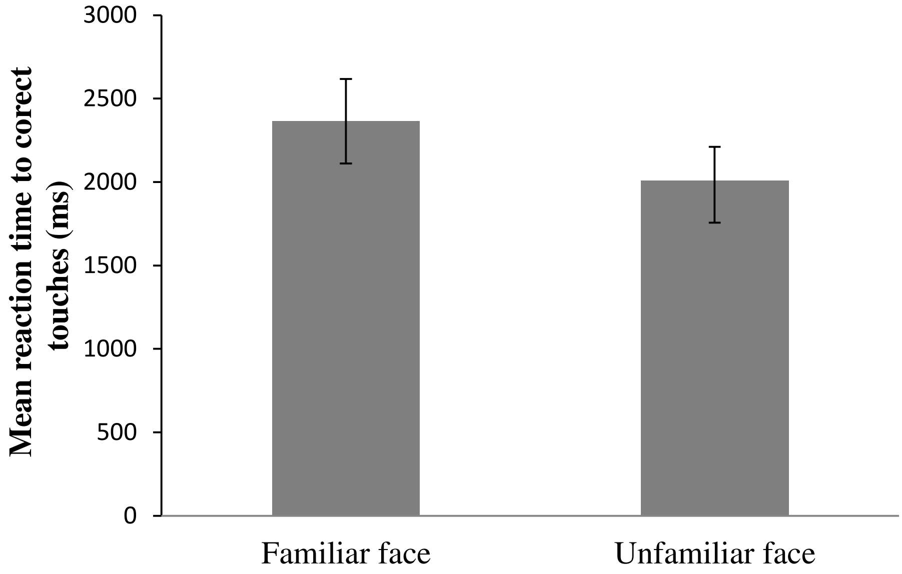

Figure 2. Mean reaction times to correct touches (ms) in reaction to familiar and unfamiliar faces. Error bars represent standard errors.

Table 1.
Overview of the number of excluded trials and included trials into the analysis in part 3.

		Familiar face	Unfamiliar face
Excluded trials			
	Experimenter errors	4	1
	Incorrect touches	7	7
Included trials			
	Correct touches	53	56
	Mean correct trials per subject	3.3	3.5