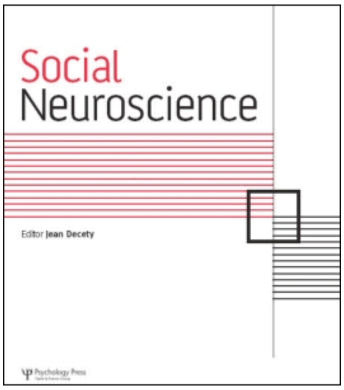

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Infants' neural processing of positive emotion and eye gaze

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Previous research demonstrated that young infants' neural processing of novel objects is enhanced by a fearful face gazing toward the object. The current event-related potential (ERP) study addresses the question of whether this effect is driven by the particular threat-value of a fearful expression or whether a positive emotion could elicit a similar response. Three-month-old infants' brain responses were measured while infants were presented with happy and neutral faces gazing toward simultaneously presented objects (Experiment 1) or happy and neutral faces gazing away from objects (Experiment 2). Then the objects were presented again without the face. While infants showed an increased neural response for happy relative to neutral faces looking towards objects, infants did not differentiate between happy and neutral faces gazing away from the objects. Furthermore, infants showed no different response to objects alone in Experiment 1. However, infants responded with an increased negative central component (Nc) indicating increased attention for objects in the neutral face condition in Experiment 2. The current results confirm previous findings showing that infants allocate increased attention to an emotional face if it directs eye gaze toward an object in the environment. However, a happy expression does not increase subsequent processing of the gaze-cued object. The findings are discussed in terms of early social cognitive development.

Keywords: Infants; ERPs; Emotional expressions; Social cognition.

INTRODUCTION

Social learning is one of the key functions of emotional expression and eye gaze processing. Our evaluation of the environment, novel objects, and strangers depends on the combined information we derive from emotional expressions and eye gaze of others. While emotional expressions are efficient means to communicate affective states, eye gaze is important to communicate the referent of an expression. For instance, people like objects more that someone else has looked at with a happy compared to a disgusted expression, whereas affective evaluations of objects that were not looked at do not depend on simultaneously perceived facial expressions (Bayliss, Frischen, Fenske, & Tipper, 2007). Our knowledge on how social cues affect brain processes in adults and infants has increased tremendously in recent years, as evidenced by extensive literature reviews

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(Frischen, Bayliss, & Tipper, 2007; Grossmann & Farroni, 2009; Hoehl et al., in press). See also Striano and Reid (2006) and Grossmann and Johnson (2007) for more general reviews on infant social cognitive development and the development of the social brain in the first year.

Infants are particularly sensitive to others' affective evaluations of the environment. When faced with a novel object, infants by 10 to 12 months of age show social referencing. That is, they search for emotional signals from adults and adjust their behavior toward the object in accordance with the emotional facial and vocal expressions of the adult (Hertenstein & Campos, 2004; Moses, Baldwin, Rosicky, & Tidball, 2001; Mumme & Fernald, 2003). Importantly, infants' responses depend on referential information. Infants do not alter their behavior toward an object if the adult expressing an emotion is out of sight, and they actively search for referential information if it is not clearly given (Moses et al., 2001). Furthermore, infants adjust their behavior only toward eye gaze cued target objects and not toward simultaneously presented distracters (Hertenstein & Campos, 2004; Mumme & Fernald, 2003). Interestingly, negative emotional expressions seem to be more effective in modulating infants' behavior in social referencing studies than positive expressions (Vaish, Grossmann, & Woodward, 2008).

Recent research has demonstrated that even young infants' neural processing of novel objects is affected by an adult's emotional facial expression and eye gaze toward the object. Using event-related potential (ERP) measures, Hoehl and colleagues (Hoehl, Palumbo, Heinisch, & Striano, 2008a) investigated 7-month-old infants' neural processing of fearful faces depending on the social context. In the first experiment infants were presented with fearful and neutral faces gazing toward small colorful objects next to the face. Infants displayed an enhanced negative central (Nc) component for fearful relative to neutral faces looking toward objects. No differential processing of fearful vs. neutral faces was found in the second experiment, in which the faces directed eye gaze to the front and thereby away from the objects. The Nc has been identified as an indicator of infant attention, with an enhanced amplitude indexing the allocation of more attention toward a salient stimulus (Reynolds & Richards, 2005; Richards, 2003). It can be concluded that fearful faces are perceived as more salient by 7-month-old infants if they indicate a concrete source of threat in the environment, i.e. if the referent of the emotional expression can be discerned. A fearful face with direct eye gaze may be very ambiguous with respect to its significance for the observer. Accordingly, amygdala activation in adults is enhanced in a social learning context in which an emotional face directs attention toward a referent in the environment compared to the emotional expression in isolation (Hooker, Germine, Knight, & D'Esposito, 2006).

A further experiment demonstrated that 3-month-old infants show an enhanced Nc component for objects that were previously gaze-cued by an adult with a fearful relative to a neutral expression (Hoehl, Wiese, & Striano, 2008b). This response was not generalized to other objects and it was not found if the adult directed eye gaze away from the object. Thus, 3-month-old infants direct increased attention towards objects that are potentially dangerous as indicated by an adult's emotional expression and gaze direction. However, in this study only the effects of fearful and neutral faces were contrasted, leaving open the question of whether the effect was driven by the threat-value of a fearful face. Possibly, a similar effect might be elicited by other emotional expressions with a different valence. In this case it could be concluded that the salience of an object is influenced by the arousal elicited by an emotional expression regardless of the particular valence of the expression.

Using the same paradigm as Hoehl et al. (2008b), the current study investigates whether infants' neural processing of a novel object can also be affected by a happy face directing eye gaze toward an object. In Experiment 1 infants were presented with happy and neutral faces gazing toward small objects. Then the objects were presented again without the face. If infants' processing of novel objects is enhanced by a happy expression that is directed toward the object, infants should show an enhanced Nc for objects that were gaze-cued by a happy relative to a neutral face. This should not be the case in Experiment 2, in which happy and neutral faces were presented with eye gaze averted away from the objects. This control experiment was conducted in order to (1) test for the effect of eye gaze direction and (2) control for memory effects. It may be that a happy face distracts infants' attention away from the object more than a neutral expression. Therefore, when presented again, objects that had been gaze-cued by a happy face may be more novel and attract more attention compared to objects that had been accompanied by a neutral face. In this case, the same pattern should be found in both experiments: an enhanced Nc for objects in the happy face condition. A third possibility is that gaze-cueing effects may be modulated by the emotional expression. Based on behavioral research it may be expected that gaze following is more difficult for infants if a happy compared to a neutral face is presented (Flom & Pick, 2005). Thus, it may be that infants are cued to the object more by a neutral face in Experiment 1, leading to an increased novelty of objects in the happy face condition. In Experiment 2, neutral faces should then distract attention away from the object more than happy faces, because eye gaze is now averted away from the objects. This might result in an increased novelty for objects in the neutral face condition. In this case we would expect an increased Nc for objects in the happy face condition in Experiment 1 and for objects in the neutral face condition in Experiment 2.

Furthermore, we were interested in infants' processing of happy and neutral faces gazing toward or away from novel objects. In previous research, infants at the age of 7 months showed an increased Nc for fearful compared to happy faces (Nelson & de Haan, 1996), happy compared to angry faces (Grossmann, Striano, & Friederici, 2007), and angry compared to fearful faces (Kobiella, Grossmann, Reid, & Striano, 2008) though the third result was not found in an earlier study (Nelson & de Haan, 1996). Importantly, previous research demonstrated that 7-month-old infants show an increased Nc for fearful compared to neutral faces gazing towards objects, but not if the face directs eye gaze away from the object (Hoehl et al., 2008a). This finding suggests that infants do not merely differentiate between emotional expressions based on low-level perceptual differences, but that they may be sensitive to referential information provided by an emotional face through eye gaze. A fearful face may be particularly salient if it indicates a concrete source of threat in the environment, i.e. if the referent of the emotional expression can be discerned. Again, the question of whether the effect is specific for fearful faces remains open. Functional neuroimaging research with adults has shown that activation of the amygdala is enhanced when object–emotion associations are learned from fearful *and* happy facial expressions relative to the perception of fearful and happy expressions alone (Hooker et al., 2006). Accordingly, it is conceivable that infants show a greater Nc response when a happy face directs eye gaze toward a novel object compared to a neutral face, as they might be sensitive to object–emotion associations in general, and not only when fearful expressions are concerned.

MATERIALS AND METHODS

Participants

Infants' parents were contacted directly after birth of their child at local hospitals. If they were interested in participating in developmental studies with their child, their names and addresses were entered into a databank and they were contacted by phone shortly before the start of the current study. All infants were born full term (37–41 weeks) and were in the normal range for birth weight. In Experiment 1, 21 infants (12 females, average age 3 months and 15 days) were included. Another 15 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. In Experiment 2, 21 infants (10 females, average age 3 months and 15 days) were included and another 8 infants were tested but could not be included due to a lack of usable trials. This drop out rate is within the normal range for ERP studies with young infants (de Haan, Pascalis, & Johnson, 2002; Halit, Csibra, Volein, & Johnson, 2004). All experiments were conducted with the understanding and the written consent of each participant's parent.

Stimuli

Stimulus material for Experiment 1 consisted of portrait photographs of one male and one female actor whose eyes were directed either to the left or to the right in a horizontal plane. Original pictures were taken from the NimStim Face Stimulus Set (www.macbrain.org). Neutral and happy pictures were taken from both actors. Their pupils and irises were moved from the middle to the left and right corner of the eyes using Adobe Photoshop CS2. Small pictures of colorful toys were displayed next to the faces to either the left or the right side, at the height of the pupils of the face, approximately 2 cm away from the eyes. The eyes were therefore effectively directed at the toys in Experiment 1. The same objects were presented in the two conditions (happy/neutral) equally often. Stimuli were 25 cm long (from the outermost edge of the object to the actor's ear on the opposite side of the picture, visual angle of 15°) and 19.5 cm high (visual angle of 12°). Objects alone were 5×5 cm of size (visual angle of 3°). In Experiment 2, the same stimulus faces and objects were presented. However, eye gaze of the faces was now averted away from the object next to the face. For objects alone, the epoch comprised a 200 ms baseline with a blank screen and 1000 ms of object presentation.

Procedure

The procedure, EEG recording and ERP analyses were the same for Experiments 1 and 2. Infants sat on their mother's lap in a dimly lit sound-attenuated and electrically shielded cabin, at a viewing distance of 90 cm away from a 70 Hz 17-inch stimulus monitor. The experiment consisted of one block with 200 trials (100 with a happy face, 100 with a neutral face). Stimuli were presented using the software ERTS (BeriSoft Corporation, Germany). The two conditions were presented to the infant in a random order with the constraint that the same condition was not presented three times consecutively and that the number of presentations of each set of stimuli was balanced in every 32 trials presented. Each trial consisted of a central attractor object (displayed for 500 ms), a happy or neutral face plus object stimulus (displayed for 1500 ms), a blank screen period with a randomly varying duration (400–600 ms), and an object displayed at the centre of the screen (displayed for 1000 ms). Every trial was followed by a blank screen period, whose duration varied randomly between 800 and 1200 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.

EEG recording and analyses

EEG was recorded continuously with Ag-AgCl electrodes from 23 scalp locations of the 10–20 system, referenced to the vertex (Cz). Data was amplified via a Twente Medical Systems 32-channel REFA amplifier. Horizontal and vertical electro-oculograms were recorded bipolarly. The sampling rate was set at 250 Hz. EEG data was re-referenced offline to the linked mastoids. A bandpass filter was set from 0.3 to 20 Hz. The EEG recordings were segmented into epochs of waveform that comprised a 200 ms baseline featuring a triangular central fixation object and 1000 ms of one static image featuring a face and object, as described above. For the elimination of electrical artifacts caused by eye and body movements, EEG data was rejected offline whenever the standard deviation within a 200-ms gliding window exceeded 80 µV at EOG electrodes or 50 µV at any electrode. Data was also visually edited offline for artifacts and matched with the infant's recorded behavior. A baseline correction was applied before averaging.

In Experiment 1, each infant contributed 10–58 face plus object trials (mean of 30) and 12–55 object only trials (mean of 28) to their average for the happy condition, and 11–55 face plus object trials (mean of 29) and 11–57 object only trials (mean of 28) for the neutral condition. In Experiment 2, each infant contributed 15–43 face plus object trials (mean of 26) and 15–45 object only trials (mean of 26) to their average for the happy condition, and 15–43 face plus object trials (mean of 27) and 10–44 object only trials (mean of 25) for the neutral condition.

ERPs were time locked to the onset of the face plus object stimulus and to the subsequent presentation of the object alone. Time windows for analysis of the Nc component were chosen based on existing literature (de Haan, Johnson, & Halit, 2003; Webb, Long, & Nelson, 2005) and on visual inspection of the averages. For statistical analysis of the responses to faces plus objects a time window was chosen around the amplitude peak of the effect from 400 to 750 ms after stimulus onset on frontocentral channels (Fz and Cz) and mean amplitude was assessed. Nc responses to objects alone were assessed in a slightly later window between 450 and 800 ms. Additionally, responses on more lateral frontal channels (F3, C3, F4, C4) were analyzed. Visual inspection of the ERPs to the face plus object stimuli in Experiment 1 suggested an earlier difference between conditions. Therefore, mean amplitude was also assessed in an earlier time window between 100 and 300 ms for face plus object trials in Experiment 1. In addition, a peak-to-trough analysis was conducted in Experiment 1 in order to test whether early effects might account for variances in the later time-window of the Nc.

RESULTS

Face plus object stimuli

ERP responses to face plus object trials for Experiments 1 and 2 are shown in Figure 1. Repeated measures analyses of variance were conducted with emotion condition (happy/neutral) and electrode (Fz/Cz) as independent factors in order to test for significant effects of emotion condition and electrode position on Nc amplitude for faces looking toward objects (Experiment 1) and faces gazing away from objects (Experiment 2). In Experiment 1 a significant main effect of emotion condition was found, $F(1, 20) = 5.25$, $p = .03$. Amplitude of the Nc was enhanced for happy faces (mean $= -17.01$, $SE = 2.5$) compared to neutral faces (mean $= -13.63$, $SE = 2.4$). No other main effects or interactions were found and no effects were found on other channels. No significant main effects of emotion condition or interactions were found in Experiment 2. The additional analysis on the earlier time window in Experiment 1 (100–300 ms) revealed a significant main effect of emotion, $F(1, 20) = 6.01$, $p = .02$. Amplitude was more negative for happy faces (mean $= -8.71$, $SE = 2.0$) relative to neutral faces (mean $= -4.57$, $SE = 1.3$). Therefore, an additional peak-to-trough analysis was conducted in order to analyze the difference of maximum peak amplitude between

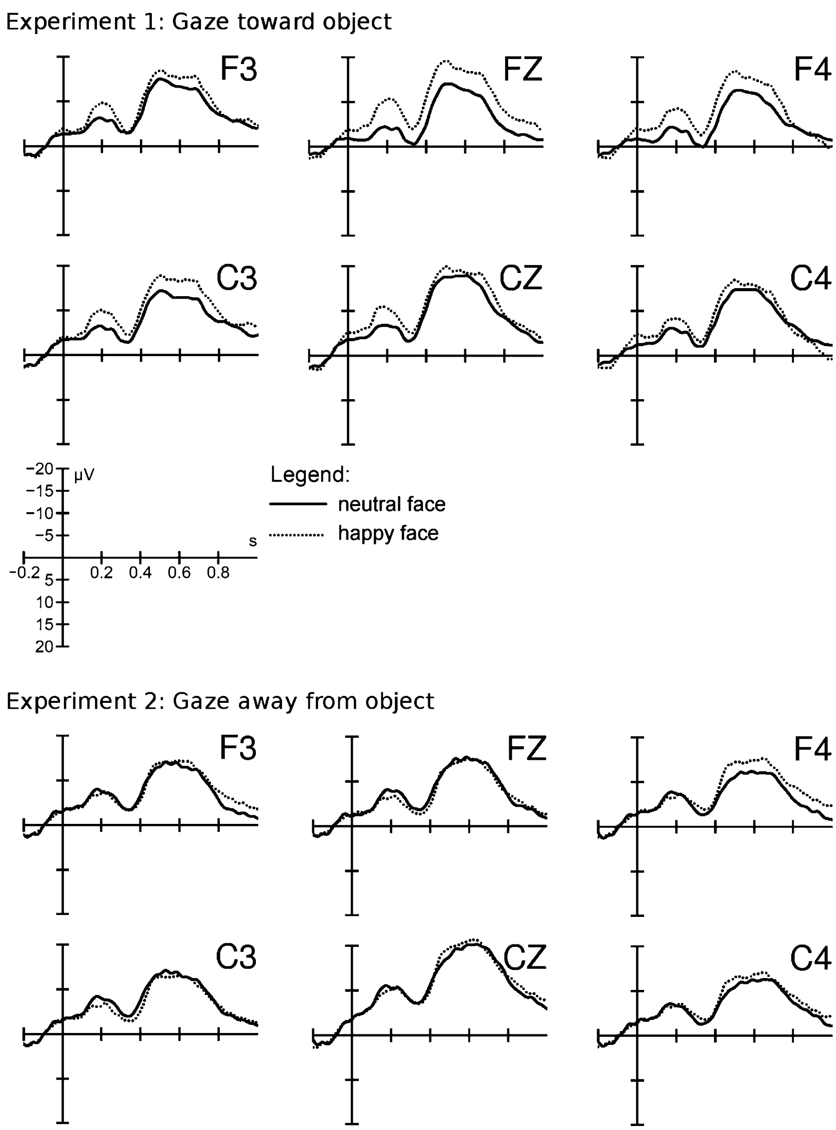

Figure 1. ERPs time-locked to the onset of the face plus object stimuli. Note that negative is plotted upwards.

200 and 400 ms to minimum peak amplitude between 400 and 750ms across conditions and electrodes. No significant effects or interactions were found.

Objects alone

ERPs for the objects alone are shown in Figure 2 for Experiments 1 and 2. The same statistical analyses were conducted as described above in order to test for significant effects of emotion condition and electrode position on Nc amplitude for objects that had been gaze-cued (Experiment 1) and objects that had been presented with a happy or neutral face gazing away from the object (Experiment 2). In Experiment 1, no significant main effects or interactions were found. In Experiment 2, we found a significant main effect of emotion condition, $F(1,\ 20) = 6.9$, $p = .016$. Amplitude of the Nc was enhanced for objects in the neutral face condition (mean $= -6.64$, $SE = 1.9$) relative to objects in the happy face condition (mean $= -1.05$, $SE = 1.7$). The same

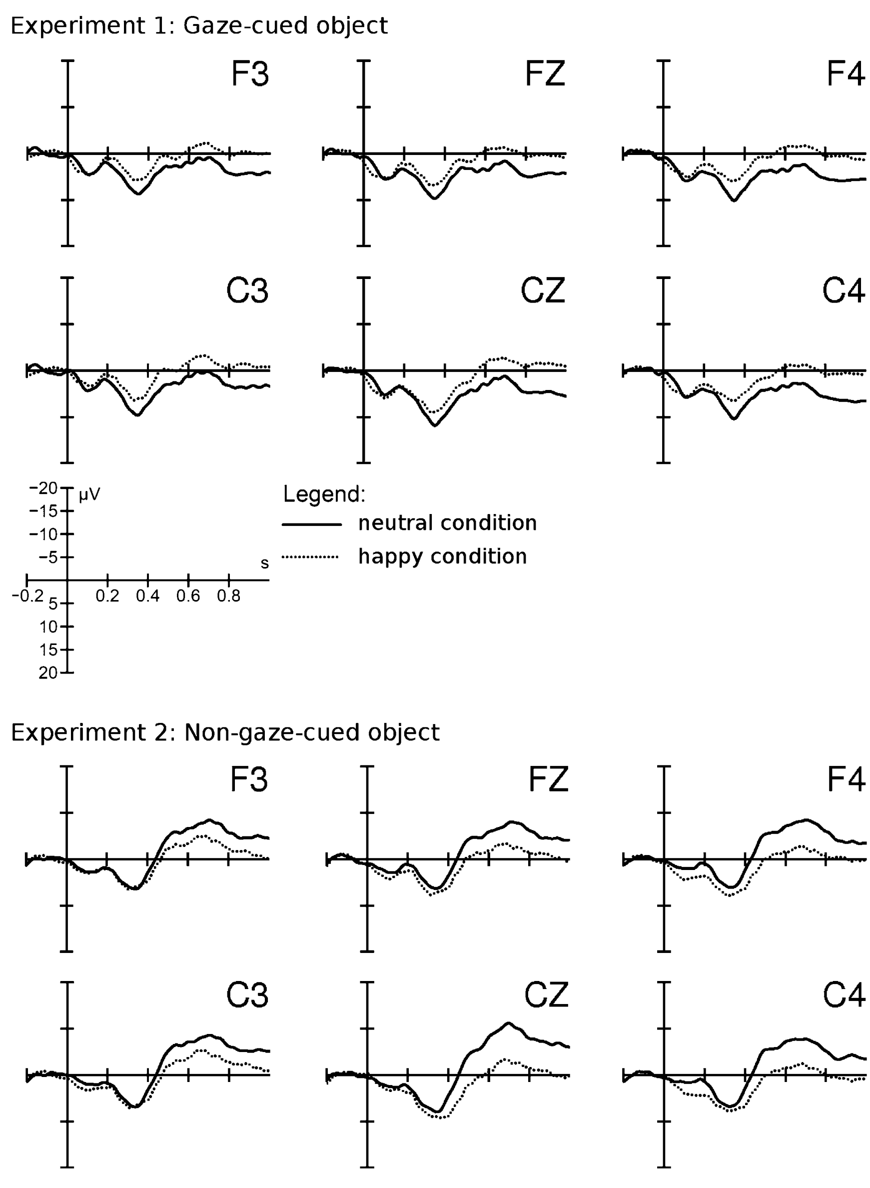

Figure 2. ERPs time-locked to the onset of the objects alone. Note that negative is plotted upwards.

effect of emotion condition on amplitude of the Nc was found on right fronto-central channels (F4/C4), $F(1, 20) = 7.2$, $p = .014$.

DISCUSSION

The current study investigated whether (1) the processing of novel objects is affected by a happy vs. neutral face gazing toward or away from the object and (2) whether the processing of happy vs. neutral faces is affected by eye gaze direction of the face in reference to a simultaneously presented object.

Three-month-old infants did not show an increased Nc response for objects that had been gaze-cued by a happy vs. neutral face. Thus, it seems that the results of a previous study using fearful faces cannot be generalized to positive emotional expressions. In this previous study 3-month-olds showed an increased Nc for objects that had before been gaze-cued by a fearful face (Hoehl et al., 2008b). This was interpreted as evidence that young infants are able to associate a novel object with a fearful facial expression, possibly because of the threat-related signal value of a fearful face. The ability to detect and understand others' social signals is essential in order to avoid danger. Therefore, it may be adaptive that even young infants' attention toward a novel object is enhanced by a fearful expression which is directed toward the object. The association of positive expressions with novel objects may not be as directly crucial for survival as the processing of negative expressions in reference to novel objects. Accordingly, an advantage of negative expressions over positive expressions has been observed in behavioral social referencing studies with older infants, suggesting evidence for a negativity bias early in development (Vaish et al., 2008). Our findings concord with this notion, though it is not clear why infants are sensitive to negative referential emotions before they are capable of active fight or flight reactions in response to threatening stimuli on a behavioral level. Future studies should thus examine the function of these early sensitivities in order to clarify their potential evolutionary basis. The existing studies leave open whether three-month-old infants can durably learn object – emotion associations and whether potential learning effects may have long-term impacts on behavioral reactions toward emotionally cued objects. A slightly different paradigm examining the cumulative effects of repeated and consistent emotion–object pairings may provide information on this question. Studies addressing the function of infants' early sensitivities regarding referential information may also elucidate the relation of these sensitivities to later social referencing behavior. It is conceivable that early attentional biases function rather automatically based on subcortical mechanisms in young infants (Hoehl, et al., 2008b), while later social referencing behavior is based on a more conscious and elaborate evaluation of the situation (Campos, Thein, & Owen, 2003). It has been demonstrated that eye gaze and threat-related emotional expressions (fear, anger) are jointly processed in the adult amygdala (Adams, Gordon, Baird, Ambady, & Kleck, 2003; Sato, Yoshikawa, Kochiyama, & Matsumura, 2004). Johnson (2005) has argued that the amygdala may be functional from birth and may help to establish the social brain network by enhancing cortical processing of socially relevant stimuli. The amygdala may be a key structure in human social development, mediating inherent perceptual biases to biologically salient stimuli and experience-dependent fine-tuning of cortical areas specialized for the processing of social information (Leppänen & Nelson, 2009). Though it is not possible to directly measure amygdala activation using ERPs, it is conceivable that the amygdala drives young infants' sensitivities for referential emotional expressions and eye gaze and thereby affects cortical processing of these salient social cues.

Interestingly, infants responded with an enhanced Nc for objects in the neutral face condition in Experiment 2. Thus, when eye gaze was averted away from the objects, objects in the neutral face condition elicited increased neural processing. One interpretation is that gaze-cueing was more effective in case of a neutral face, thus distracting infants' attention away from the object more in the neutral face condition compared to the happy face condition in Experiment 2. Consequently, objects in the neutral face condition were less thoroughly encoded during the first presentation with the face and elicited a novelty response when presented again without the face. In accordance with this interpretation in previous research, infants showed reduced gaze following if the experimenter posed a happy or sad expression compared to a neutral face (Flom & Pick, 2005). This was attributed to infants' limited flexibility of attention when perceiving an emotional expression together with social attention cues. Though overt gaze following was not examined in the present study, in both studies infants' attention may have been overstrained by the presentation of an emotional face together with gaze cues. Consequently, infants' attention may be more flexibly driven in the direction of gaze cues in case of a neutral face. In the study by Flom and Pick only happy and sad expressions were contrasted to neutral faces. In contrast, a fearful expression may enhance gaze following, because of the high relevance for correct object–emotion association in the case of fear. Accordingly, fearful expressions can potentiate automatic orienting in the direction of eye gaze in adults (Tipples, 2006). If infants' attention was drawn away by the averted eye gaze of a neutral face more than in the happy face condition, this might have affected infants' subsequent processing of the object leading to an enhanced Nc for the object in the neutral face condition due to its greater novelty. However, in this case a stronger gaze-cueing effect for neutral faces should have also been observed in Experiment 1. Consequently, objects in the neutral face condition should have been more thoroughly encoded, leading to an enhanced Nc for objects in the happy face condition. In fact, there was a slightly enhanced Nc for happy objects in Experiment 1, though the difference was not significant.

Another possibility is that more general issues relating to infants' cognitive capacities or attentional load may have driven the observed effects. Possibly less information was contained in objects in the neutral trials, leading to more available attention resources and consequently to an increased Nc. However, this should have led to a similar pattern of results in Experiment 1, which was not the case. Furthermore, the Pb (positive before) component rather than the Nc has been related to ease of processing in previous research (Karrer, Karrer, Bloom, Chaney, & Davis, 1998), but no differences across conditions were found in this component.

When looking at infants' responses to face plus object stimuli, infants showed an increased negativity for happy faces gazing toward objects relative to neutral faces gazing toward objects (Experiment 1), whereas no difference was found when eye gaze was averted away from the objects (Experiment 2). This finding is an interesting addition to previous research on referential processing of emotional expressions. In a previous ERP study 7-month-old infants showed an increased Nc for fearful vs. neutral faces gazing toward objects, but not if gaze was averted away from the objects (Hoehl et al., 2008a). These findings suggest that emotional expressions are particularly salient for infants if they are directed toward something in the environment. This attention bias toward object–emotion associations may be crucial for the development of social learning. Our findings show that increased processing of referential emotion is not specific for fearful emotional expressions but can be elicited by a happy face as well. Accordingly, amygdala activation in adults is sensitive to object–emotion associations for fearful and happy faces (Hooker et al., 2006). In contrast to earlier findings with 7-month-olds and fearful faces, we also found an earlier negativity which was significantly enhanced for happy faces gazing toward objects. A peak-to-trough analysis suggested that the later Nc effects may in part be driven by this earlier negativity. Unfortunately, the function of this early component is still relatively unclear, making the interpretation of the effect more difficult. The finding of an earlier effect for referential happy faces compared to fearful faces in previous work is somewhat counterintuitive given the relevance of rapid processing of fear and the attention capturing effects of fearful faces in previous work (Peltola, Leppänen, Palokangas, & Hietanen, 2008). However, it makes sense that happy expressions are processed in a rapid manner even in early infancy. In the first months infants most frequently perceive positive expressions, and only by 7 to 8 months are they confronted more and more frequently with negative expressions (Campos et al., 2000). Correspondingly, happy expressions are most consistently discriminated from other expressions in the first months (see de Haan, 1998; Leppänen & Nelson, 2006, for reviews) and even shortly after birth (Farroni, Menon, Rigato, & Johnson, 2007). Though a negativity bias has been observed in infants' social referencing behavior (Vaish et al., 2008), happy faces seem to be the most readily identifiable expressions in infancy and childhood (Ekman, 1982; Widen & Russell, 2003). Thus, it seems that while negative expressions have a more pronounced impact on infants' processing of and behavior toward novel objects, happy faces may be more familiar and possibly easier to process for young infants. However, we have not examined infants' familiarity with emotional expressions in the current study and it is not clear whether familiarity with an expression necessarily promotes more rapid processing of the expression. Another open question is whether neutral faces may be more novel for infants compared to happy faces, since work with children suggests that neutral faces are particularly difficult to recognize and label correctly for young children (Herba & Phillips, 2004) and in some studies even elicit more amygdala activation than fearful faces (Thomas et al., 2001). In any case, differences in familiarity with happy, neutral and fearful faces *per se* cannot explain the specific pattern of findings in the current and previous studies. If infants simply devoted more processing resources to more (happy) or less (fearful) familiar emotional expressions compared to neutral faces, this should not be affected by eye gaze in reference to external objects.

CONCLUSIONS

The current experiment provides evidence that 3-month-old infants devote more processing resources to a happy face directing eye gaze toward an object compared to neutral faces and faces with averted gaze. This suggests that even very young infants are sensitive to object–emotion associations when happy faces are presented. However, subsequent processing of the object was not affected by the expression of a face looking toward it. This may indicate that more frequent and/or prolonged object–emotion presentations may be necessary in order to affect young infants' processing of a novel object durably if happy expressions are presented. However, since older infants' behavior toward a novel object is less affected by a positive compared to a negative expression, it is also conceivable that infants do not direct increased attention to an object associated with a happy face, but only if potential threat is signalled by the expression. Further studies are needed to clarify the functions of infants' early sensitivities to referential emotional expressions and their relations to later social referencing skills. These studies should also include other emotional expressions. Theoretical accounts of the development of emotion and gaze processing should take account of the combined neural processing of both kinds of information in early infancy (Hoehl et al., in press).

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