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Eye contact influences neural processing of emotional expressions in 4-month-old infants

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Eye gaze is a fundamental component of human communication. During the first post-natal year, infants rapidly learn that the gaze of others provides socially significant information. In addition, infants are sensitive to several emotional expressions. However, little is known regarding how eye contact influences the way the infant brain processes emotional expressions. We measured 4-month-old infants' brain electric activity to assess neural processing of faces displaying neutral, happy and angry emotional expressions when accompanied by direct and averted eye gaze. The results show that processing of angry facial expressions was influenced by eye gaze. In particular, infants showed enhanced neural processing of angry expressions when these expressions were accompanied by direct eye gaze. These results show that by 4 months of age, the infant detects angry emotional expressions, and the infant brain processes their relevance to the self.

Keywords: infants; EEG; eye gaze; social cognition; ERP

INTRODUCTION

The detection of one another's eye contact is essential for effective social learning and communication among humans. Eye contact provides information about the target of others' expressions and clues about their communicative intentions and future behavior (Baron-Cohen, 1995). A sensitivity to eye contact is robust in early human ontogeny. For instance, newborn infants look reliably longer at faces with direct gaze as compared with averted gaze (Farroni *et al.*, 2002). By 4 months of age, the infant brain manifests enhanced processing of faces with direct gaze as compared to averted gaze (Farroni *et al.*, 2002). Also, at this age, the infant brain manifests enhanced processing of objects that have been cued by the direction of others' gaze (Reid *et al.*, 2004), indicating that gaze is used to determine what is socially relevant to the infant in the surrounding environment.

In addition to the early sensitivity to eye contact, young infants discriminate among a range of facial expressions directed at them (see Walker-Andrews, 1997, for a review). For instance, by 3 months of age, infants visually discriminate between happy and angry facial expressions (Barrera and Maurer, 1981). Using a peek-a-boo paradigm, Montague and Walker-Andrews (2001) demonstrated that infants as young as 4 months discriminated others' emotional expressions (fear, anger, happiness or surprise) and responded in a socially appropriate manner. Even though such research indicates an early sensitivity to eye contact and emotional expressions, they do not indicate whether infants associate particular expressions with specific mental states.

Despite a wealth of research on infants' processing of eye contact and facial expressions, nothing is currently known about processes by which the infant brain detects emotional expressions in combination with eye direction. It is known that among adults gaze direction influences the neural systems involved in expression processing (Adams *et al.*, 2003). Adams *et al.* (2003) found that the human amygdala, when confronted with angry and fearful faces in direct *vs* averted gaze, was activated consistent with an adaptive social response, with a higher activation in the amygdala to angry averted and fearful direct gaze, although this result is controversial (Sato *et al.*, 2004).

Research into how adults process emotions suggests that behavioral and electrophysiological correlates of emotion discrimination are sensitive to aspects of emotion processing, such as encoding. Schupp *et al.* (2004) found in their behavioral ratings of their stimuli that the angry direct gaze was more threatening and arousing than the angry averted gaze. Schupp *et al.* (2004) also examined the late positive potential (LPP) of the event-related potential (ERP). Their data suggested increased positivity for threatening faces if the eyes were directed toward the subject when compared with those derived from threatening faces with gaze directed away from the subject. Even though the issue remains of how such

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adult data relates to infant ERP and the processing of emotions in early development, these results indicate clear differential processing of threatening *vs* neutral or friendly faces and the manifestation of such differential processing at the electrophysiological level.

Research on gaze direction with adults also indicates that faces provide strong cues, with eyes assuming particular social importance (Kampe *et al.*, 2001). These authors found that the perceived attractiveness of an unfamiliar face increased brain activity in the ventral striatum when observing direct gaze but not in the case of averted gaze. They linked the direction of gaze to the activation of dopaminergic regions that are related to reward prediction. These results suggest that reward systems may be engaged during the initiation of social interactions provided that there appears to be a social reward in interacting with an individual. Such work has never been conducted with a developing population. The question consequently remains open whether this system that rewards potentially positive social encounters is active in early development or not.

Despite the importance of eye gaze in infants' ability to determine the social significance of emotional expressions (i.e. whether these expressions are intended for the self or someone else), infants' sensitivity to eye gaze direction and emotional expressions have never been manipulated in experimental contexts. One way to combine these topics is to investigate the neural underpinnings of cognitive processes associated with the observation of emotional eye gaze direction. ERPs are a useful tool in infancy research as they provide information about neural activity before, or in absence of, an overt response. One infant ERP component that may be involved in maintaining information over a period of time is the positive slow wave (PSW). This component has been found to be larger for novel than for familiar stimuli during the processing of faces and objects by 6-month-old infants (Nelson, 1997; de Haan and Nelson, 1999) and in typically developing toddlers (Dawson *et al.*, 2002). It is thought to index the detection of novelty (de Haan and Nelson, 1999) and attention (Reid *et al.*, 2004; Reynolds and Richards, 2005). Interestingly, ERP research with adults suggests that threatening faces elicit enhanced LPPs (Schupp *et al.*, 2004). These authors proposed that the LPP reflected the more complex or facilitated perceptual processing of these expressions relative to other emotional expressions. The data from adults would, therefore, suggest that infants may process angry emotional expressions differentially, dependent on the direction of gaze.

We assessed how 4-month-old infants process neutral, happy and angry facial expressions that are either directed toward or away from them. We predicted that direct gaze would provoke a larger-amplitude slow wave positivity than that elicited by averted gaze and that this will be evident across emotional expressions. The assessment of PSW is due to its association in past research with novelty detection, the partial encoding of information and attention. Given the short attention span of infants at 4 months of age and to ensure enough trials for adequate averaging of the ERP data, we conducted the present research with each emotional expression as a separate experiment. We also investigated difference scores between subjects.

EXPERIMENT ONE: NEUTRAL FACES

Materials and method

Participants. Thirty-three infants (13 males and 20 females) were tested, with an average age of 4 months, or 132 days $\pm$ 11 days. All infants were born full term (37–41 weeks) and were in the normal range for birthweight. Another 17 infants were tested, but were excluded from the final sample as a result of fussiness ($n = 3$) or failing to reach the minimum requirements for adequate averaging of the ERP data ($n = 14$). The minimum criteria for inclusion was 15 trials per condition; however, each infant contributed 15–47 (mean of 25.3) trials to their average for the direct gaze and 15–50 (mean of 23.4) to their average for the averted gaze from a mean of 97.5 viewed presentations of the stimuli.

Stimuli. Three photos of a female actress producing a neutral expression were created using a digital camera. The actress' gaze was directed straight-on to the viewer (direct gaze) or averted to one side (averted gaze). Figure 1 (top row) illustrates the stimuli used in this experiment.

Procedure

Infants sat on their parent's lap in a dimly lit sound-attenuated and electrically shielded cabin, at a viewing distance of 50 cm away from a 70 Hz 17 inch stimulus monitor. The experiment consisted of one block with 150 trials with direct and averted gaze, each presented with a 50% probability. The direction of averted gaze (i.e. left or right) was also varied between infants.

Each trial was preceded by a black-and-white dot pattern presented in the middle of the screen for 500 ms in order to attract attention to this location and to adapt the visual system to the brightness of the subsequent stimulus. The trial stimulus was presented in the center of the screen for 1000 ms. Between the presentation of the stimuli, the screen was blank for a random period of between 800 and 1000 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. Electroencephalogram (EEG) was recorded continuously, and the behavior of the infants was also video-recorded throughout the session.

EEG recording and analysis

EEG was recorded continuously with Ag–AgCl electrodes from 27 scalp locations in an extended 10–20 system, referenced to the vertex (Cz). The ground electrode was

Fig. 1 Experimental stimuli. Stimuli were color photographic images of female faces directing their gaze straight-on to the viewers (direct gaze, central panels) or averted to one side (averted gaze, left and right panels) with (top) neutral, (middle) happy and (bottom) angry emotional expressions.

positioned at electrode position FP1. Data was amplified via a Twente Medical Systems 32-channel REFA amplifier. Bipolar horizontal (outer canthi) and vertical (above and below the right eye) electro-oculargrams (EOGs) were recorded to control artifacts caused by eye movements. The electrical potential was amplified with 0.3–20 Hz filter bandpass, digitized at a 250 Hz sampling rate and stored on computer disk for the off-line analysis. EEG data was re-referenced off-line to the linked mastoids.

The EEG recordings were segmented into epochs of waveform that comprised a 200 ms baseline featuring a black-and-white dot pattern and 1000 ms of direct or averted gaze. For the elimination of electrical artifacts caused by eye and body movements, EEG data was rejected off-line whenever the raw amplitude within a 200 ms gliding window exceeded 80 μV for the eye electrodes and 50 μV at any individual electrode. Data were also visually edited off-line for artefacts. Trials in which infants had not looked at the screen were identified from video recordings and were excluded from further analysis.

Previous research has indicated that 4-month-old infants are sensitive to eye gaze direction (Farroni *et al.*, 2002). However, a direct comparison between the present study and that of Farroni *et al.* (2002) is not possible for several reasons. First, Farroni *et al.* (2002) restricted their assessment of the infant ERP to posterior channels of the sensor array in locations associated with the 'infant N170' component, whereas the PSW effect assessed in the present study is usually located in central or fronto-central regions (de Haan and Nelson, 1997; Reynolds and Richards, 2005). Further, it was not possible for us to analyze occipital leads [as in the study by Farroni *et al.* (2002)] as our sensor layout contained only one channel per occipital hemisphere, referenced to the linked mastoids, whereas Farroni *et al.* (2002) utilized 12 electrodes referenced to the 'average' reference. We were thus unable to verify the original Farroni *et al.* (2002) finding due to differences between the two EEG systems.

For statistical analysis a time window was chosen, reflecting the onset of the PSW (700 ms) until the end of the epoch (1000 ms) after stimulus onset. ERPs were evaluated statistically by computing the mean amplitude in the two conditions in the following regions of interest (ROIs): left anterior (F3, C3), central anterior (FZ, CZ) and right anterior (F4, C4). Variances of ERPs were analyzed by a 2×3 repeated-measures ANOVA. Analyzed factors were (i) gaze direction (direct $\times$ averted) and (ii) hemispheric lateralization (left, central or right).

Results

We assessed the ERP difference in the direct gaze and averted gaze conditions by considering the mean amplitude in the two conditions. An ANOVA was performed in fronto-central regions as previous research with infants has suggested that it is at this location that the PSW is most evident (e.g. de Haan and Nelson, 1999). Further, our preliminary analysis of the grand average indicated that this was the case with our data (Figure 2).

The ANOVA indicated no main effect of gaze or significant interactions between scalp location and gaze. Assessment of the waveform at earlier epochs (200–400 and 400–700 ms) utilizing the same channels and statistical parameters did not detect any other effects.

EXPERIMENT TWO: HAPPY FACES

Materials and method

Participants. Twenty-eight infants (11 males and 17 females) were tested, with an average age of 4 months, or 126 ± 12 days. All infants were born full term (37–41 weeks) and were in the normal range for birthweight. Another 28 infants were tested but were excluded from the final sample as a result of fussiness ($n = 12$) or failing to reach the minimum requirements for adequate averaging of the ERP data ($n = 16$). The minimum criteria for inclusion was 15 trials per condition, however, each infant contributed 15–50 (mean of 23.1) trials to their average for the direct gaze and 15–51 (mean of 22.2) to their average for the averted gaze from a mean of 106.9 viewed presentations of the stimuli. All studies were conducted with written consent of each participant's parent.

Stimuli. The stimuli were the same as those described in Experiment One, however the actress was displaying a happy emotional expression. Figure 1 (middle row) illustrates the stimuli used in this experiment.

Procedure

The procedure was the same as that outlined in Experiment One.

EEG recording and analysis

The EEG recording was the same as that outlined in Experiment One.

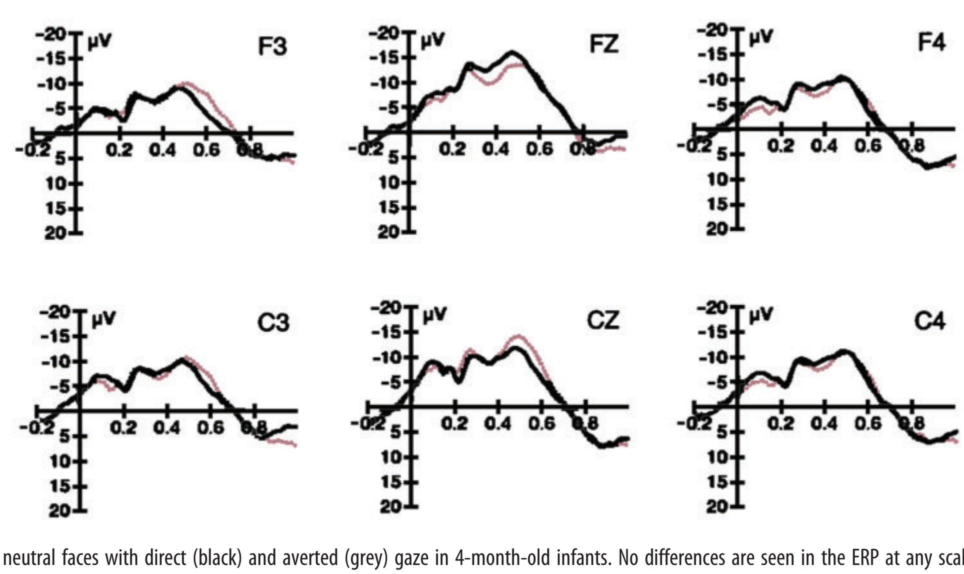

Fig. 2 ERPs recorded to neutral faces with direct (black) and averted (grey) gaze in 4-month-old infants. No differences are seen in the ERP at any scalp location. Note: negative voltage is plotted upwards.

Results

We conducted an ANOVA with the same statistical parameters as outlined in Experiment One. See Figure 3 for an example of the grand average waveform over fronto-central scalp sites.

The ANOVA indicated no main effect of gaze or significant interactions between scalp location and gaze. Assessment of the waveform at earlier epochs (200–400 and 400–700 ms) utilizing the same channels and statistical parameters did not detect any other effects.

EXPERIMENT THREE: ANGRY FACES

Materials and method

Participants. Twenty-three infants (12 males and 11 females) were tested, with an average age of 4 months, or 126 ± 12 days. All infants were born full term (37–41 weeks) and were in the normal range for birthweight. Another 27 infants were tested but were excluded from the final sample as a result of fussiness ($n = 10$) or failing to reach the minimum requirements for adequate averaging of the ERP data ($n = 17$). The minimum criteria for inclusion was 15 trials per condition, however, each infant contributed 15–40 (mean of 23.2) trials to their average for the direct gaze and 15–39 (mean of 23.3) to their average for the averted gaze from a mean of 100.1 viewed presentations of the stimuli.

Stimuli. The stimuli were the same as those described in Experiment One, however the actress was displaying an angry facial expression. Figure 1 (bottom row) illustrates the stimuli used for this experiment.

Procedure

The procedure was the same as that outlined in Experiment One.

EEG recording and analysis

The EEG recording was the same as that outlined in Experiment One.

Results

We conducted an ANOVA with the same statistical parameters as outlined in Experiment One. See Figure 4 for an example of the grand average waveform over fronto-central scalp sites.

The ANOVA indicated a main effect of gaze [$F(1,22) = 5.95$, $P = 0.023$] reflecting a larger mean amplitude PSW for the direct gaze ($M = 8.76$, s.d. = 15.7) when compared with the averted gaze ($M = 2.29$, s.d. = 13.3); see Figure 4 for an illustration of the waveform for the two conditions. With negative plotted upwards, the PSW can be seen in channels from 800 ms as the downward deflection of the ERP waveform. There were no significant interactions between scalp location and gaze ($P = 0.26$). Assessment of the waveform at earlier epochs (200–400 and 400–700 ms) utilizing the same channels and statistical parameters did not detect any other statistically significant effects.

DIFFERENCE ANALYSIS

We also assessed difference scores obtained for each subject in each experiment that consisted of direct *vs* averted gaze for one emotion. We subtracted averted from direct gaze in all emotions. We were thus left with three sets of difference scores, with one for each emotion. We compared these scores in a univariate analysis of variance with each emotion as a between-subjects factor. The overall effect of emotion did not reach significance [$F(2,81) = 1.947$, $P = 0.149$]. However, these experiments were designed as within-subjects comparisons and thus do not have the

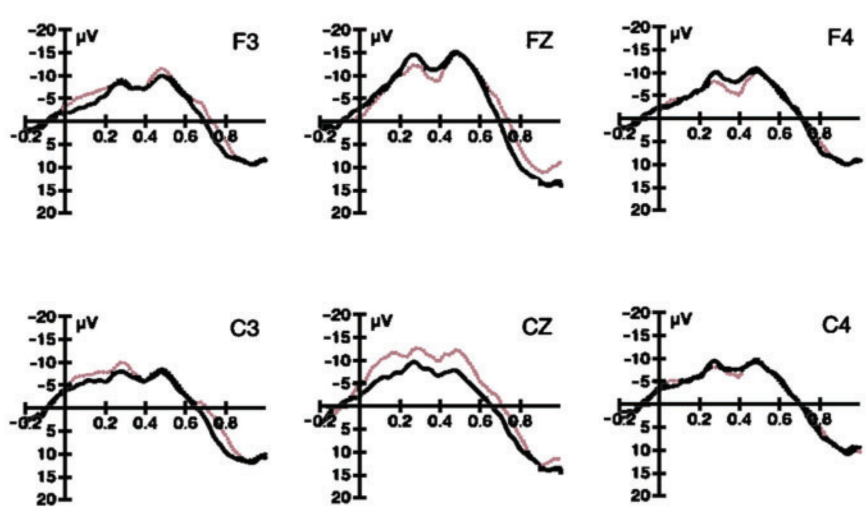

Fig. 3 ERPs recorded to happy faces with direct (black) and averted (grey) gaze in 4-month-old infants. No differences are seen in the ERP at any scalp location. Note: negative voltage is plotted upwards.

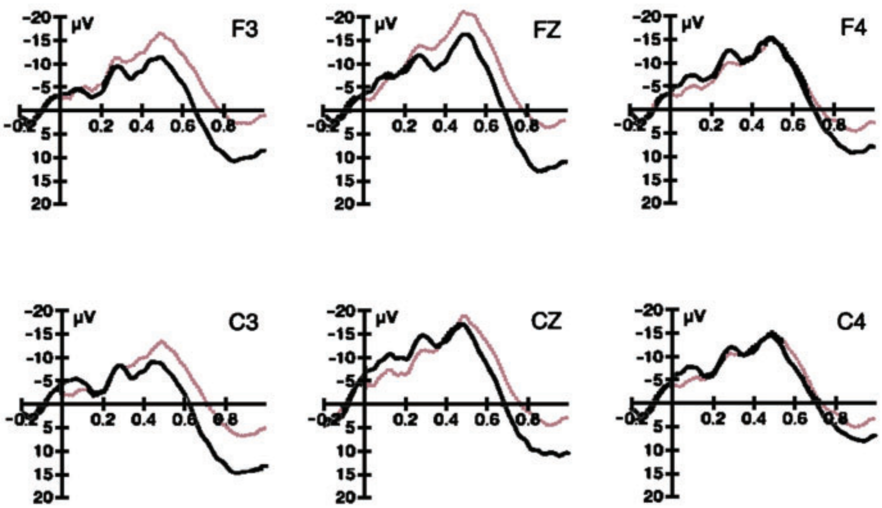

Fig. 4 ERPs recorded to angry faces with direct (black) and averted (grey, gray) gaze in 4-month-old infants. All electrodes over the central and frontal cortex recorded an enhanced positive slow wave response (from 700 ms after stimulus onset) to the angry faces with direct gaze compared with the faces with averted gaze. This can be seen as the divergence of the downward curve of the ERP for direct and averted gaze from 700 ms after stimulus onset. Note: negative voltage is plotted upwards.

statistical power needed to make clear between-subjects comparisons. However, see Figure 5 for a summary of the recorded microvoltage over fronto-central areas during the positive slow wave.

DISCUSSION

In the present series of experiments, we assessed 4-month-old infants' ERP responses to the perception of happy, neutral and angry facial expressions that are either directed toward or away from them. We found no effect of eye gaze for faces depicting happy and neutral expressions. There was an effect for faces displaying an angry emotional expression, with enhanced amplitude for those faces with eyes directed forwards relative to those faces with eyes averted. The ERP finding relates to the PSW, which in previous studies relating to object processing has been interpreted as indexing memory encoding or discrimination (de Haan and Nelson, 1999; Nelson, 1997) and has also been associated with cognitive mechanisms related to attention (Reynolds and Richards, 2005).

The results of the present study suggest that infant attention is increased if the presented stimuli are novel and socially relevant. Farroni *et al.* (2002) provided evidence indicating enhanced face processing in the infant brain when viewing faces with direct gaze. One logical question that followed was what important social information may be contained in the 'enhanced face processing' described by Farroni and colleagues. Here we show that infants differentially process direct and averted angry faces, whereas they do not with happy and neutral faces. This result suggests a neural mechanism that detects novel socially relevant information.

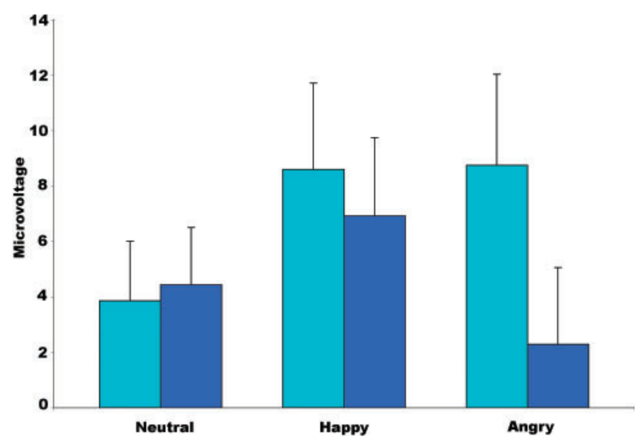

Fig. 5 Summary bar graph depicting microvoltage over fronto-central areas of the positive slow wave (700–1000 ms) for the three experiments. Light green represents direct gaze and dark blue represents averted gaze. Error bars represent standard error for each experiment.

An alternative explanation for why we find differential processing of the angry emotional expression but not the happy or neutral expressions is that infants find the angry face novel, thereby facilitating attention as indexed by the PSW. The enhanced attentional state of the infant allows a more rapid encoding of featural information contained in the face including the gaze direction of the eyes. As young infants prefer to look at faces depicting direct *vs* averted eyes (e.g. Johnson and Morton, 1991) we find differential processing of direct and averted gaze. However, such an explanation is problematic as the detection of gaze direction has been shown to occur earlier in the waveform—and is thus processed earlier—than the effects that we have found on the PSW. Prior research would suggest that the eyes are attended to prior to the encoding of any emotional information. However, evidence against this interpretation of the data derives from research with adults where emotional information and eye gaze appear to be processed interdependently (Ganel, Goshen-Gottstein and Goodale, 2005). Perhaps most convincingly, we found no difference for direct *vs* averted eyes when infants viewed happy and neutral faces, again suggesting that the PSW effect is not merely due to infants' inclination to look toward direct gaze as compared to averted gaze.

A final explanation for the finding that angry emotional expressions elicit enhanced amplitude with direct eyes relative to those faces with averted eyes is based on infant experiences of emotional expressions. Specifically, by 4 months, infants may have very rarely seen angry faces, whereas the manifestation of positive or neutral affect may be more common in their environment (Campos *et al*., 2000). As past experiences have not provided infants with information on the emotional content of an angry face, it is therefore less familiar. This lack of familiarity (or increased novelty) may be manifest in the PSW. As the social meaning of the angry face is unclear, when the eyes are oriented directly toward the infant, it is potentially more socially relevant. The ambiguity surrounding the social information is subsequently indicated in the infant's attention and this is indicated by the enhanced PSW (Reynolds and Richards, 2005). Further work is required to assess this hypothesis by varying infants' experience with various expressions depicting threat and novelty and comparing these results to familiar and non-threatening non-social stimuli. Additionally, the testing infants at older ages who have presumably had more experience with angry facial expressions may yield further information on the ontogenetic patterns associated with socially relevant information. It is known, for instance, that by 12 months of age, infants use facial cues to evaluate potential threat and are thus familiar with angry faces (e.g. Klinnert *et al*., 1986).

There is also the possibility that these data represent the processing of distinct emotional cues by infants. The finding that angry faces with direct gaze are differentially processed from those with averted gaze, whereas the fact that this is not the case for happy and neutral expressions may tie in with research into adult processing of emotional expressions. First, Adams *et al.* (2003) showed that during the perception of angry and fearful faces, differential processing occurred in the human adult amygdala that was consistent with a 'neural system responsive to potential threat' (p. 1536). It is possible that a similar cognitive system exists early in infancy. However, as ERPs are believed to assess cortical rather than deep brain structures (Makeig *et al*., 2004), it is possible that the infant PSW is not related to amygdala activation. To date, source localization techniques have not been applied to the infant PSW and any associations between the amygdala and cortical activity in infancy are yet to be investigated. The assessment of a neural system related to the detection of threat in infants is clearly an area of further research. This is particularly the case as the results of the present study are difficult to explain on the basis of novelty alone. Specifically, if angry emotional expressions are novel, then direct and averted gaze should equally produce relatively larger PSW effects than those seen in familiar emotional expressions.

In the realms of social cognition there are many implications of the results of this study. This study suggests that infants are sensitive to the direction of angry gaze. This neural sensitivity to the direction of angry gaze suggests that infants may be primed to detect novel emotions that are directed toward them. We predict that infants would also manifest similar PSW responses to faces depicting unfamiliar emotions such as surprise, disgust and fear, whereas we would not predict differences for familiar facial expressions such as smiling and laughter. This has clear consequences for aspects of social information that infants are more likely to learn. Novel aspects of the environment raise levels of attention. Given that increased attention correlates with rapid learning (Richards, 1998), the results of this study suggest that infants are primed to detect and differentially attend to new components of social interactions. However, the issue of whether these results relate to the finding in adults that we are automatically sensitive to the presence of angry faces (Hansen and Hansen, 1988) must remain open. Further research must first be conducted whereby eye gaze direction is modulated on faces depicting other novel emotions, such as fear, disgust and surprise prior to any conclusion on whether the PSW indexes information pertaining to only angry faces.

There are some strong reasons why infants may be sensitive to direction of gaze in negative emotional expressions. Evolutionary theorists may predict that unusual social phenomena would be particularly relevant for infants as they may relate to imminent changes in the equilibrium of the environment (for example, Öhman, Lundqvist and Esteves, 2001). As such, the monitoring of novel emotional expressions may help infants predict state changes in the environment. Interestingly, neural systems associated with the detection of state changes (the so-called hypothalamic-pituitary-adrenal, HPA, axis) are altered in abused children (e.g. Glaser, 2000). If the HPA axis is damaged in abused children, many have argued that it is due to the continued and aberrant arousal of this system in order for the child to be primed for situations where instant action is required, such as confrontation or flight. The present study suggests that the detection of novel emotions is important for the infant in terms of predictive capabilities.

The current research demonstrates an important interaction of gaze and emotional cues on infant processing of human faces. This work extends the findings of Farroni *et al*., (2002) by providing further social information to the infant. Whatever the exact foundation for the result whereby angry faces with direct gaze manifest a larger PSW then angry faces with averted gaze, and no differences occurred in slow wave activity for neutral or happy faces with direct and averted gaze, the present experiments extends our knowledge on infant processing of emotions. Clearly by 4 months of age, the infant brain processes eye gaze direction and emotional expressions. Critical issues for further research include finding if this effect is apparent from birth or whether particular social experiences are required for such a neural response. The current findings are the first step in understanding how eye gaze influences the processing of facial expressions. In sum, eye gaze and emotional expressions are not processed in isolation from each other in the infant brain.

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