Infants' attention is biased by emotional expressions and eye gaze direction

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This study investigates infants' processing of emotional expressions in combination with referential eye gaze cues. In experiment 1, 7-month-old infants' neural responses to fearful and neutral faces, which were looking at a novel object, were assessed. Infants' attention, as indexed by the negative central component of the event-related potential, was enhanced when the adult gazed at the object with a fearful expression compared with a neutral expression. In experiment 2, no effect of emotion on amplitude of the negative central was found when the face directed eye gaze at the infant and away from the object. We conclude that by 7 months, infants use emotional expressions in triadic person-object-person contexts to detect threat in the environment. *NeuroReport* 19:579–582

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Introduction

The communication of threat is crucial and fast processing of this information is adaptive already in infancy. Two of the most important social cues that can be used to communicate threat are facial expressions and eye gaze direction. Detection of eye gaze is a phylogenetically ancient mechanism [1], and primates use eye gaze, for instance to express emotional states or to attract others' attention toward objects in the environment [2].

Human infants are sensitive to others' eye gaze direction from birth [3]. By 3 months of age, infants use eye gaze to guide their own attention and to facilitate encoding of novel objects [4,5]. Despite growing evidence that infants use eye gaze to learn about their environment, little is known about how young infants use social cues to detect potential threat.

In addition to their sensitivity for eye gaze direction, infants are also sensitive to emotional expressions in face and voice [6,7], especially in ambiguous or disturbing situations [8]. By the end of the first year, infants show social referencing, that is, they actively seek and use emotional expressions provided by others to disambiguate potentially dangerous situations and to guide their own behavior [9]. It is, however, not yet clear at what age social referencing emerges, as almost all studies in this field investigated infants' behavioral responses from the age of 10–12 months onwards [8,9]. As infants constantly encounter situations they perceive as 'novel', it is likely that infants' attention system is affected by eye gaze and emotional expressions much earlier. Event-related potentials (ERPs) may be the more sensitive measure to explore this question in young infants compared with overt behavioral responses that require a sophisticated motor system.

Fearful facial expressions are particularly interesting in the context of threat detection [10]. In adults, processing of fearful faces is facilitated when eye gaze is averted to the side compared with direct gaze [11]. This indicates that fearful faces with averted gaze are an indicator of threat, because the eyes might be directed at something dangerous in the environment [12]. In a recent study with infants, however, no difference in neural processing of fearful faces with direct or averted gaze was found in 7-month-olds [13]. This might be owing to the fact that faces in this study were presented in a dyadic face-to-face context, without an external referent of the adult's eye gaze. Possibly, infants need a concrete referent of the adult's gaze to be sensitive to the threat-related signal value of a fearful expression. We reasoned that fearful faces with gaze averted to the side and looking toward an object next to the face would elicit enhanced neural processing in 7-month-old infants relative to fearful faces with gaze directed at the infant and neutral faces.

To test for this hypothesis, we conducted two experiments in which infants' processing of fearful (experimental condition) and neutral (control condition) faces was assessed in different social contexts. In experiment 1, infants saw fearful or neutral faces gazing toward novel objects (triadic context). We hypothesized that infants' allocation of attention would be enhanced in the fearful face condition compared with the neutral face condition, as indicated by an enhanced Nc (negative central) component. The Nc is a well-documented component in infant ERP research and its amplitude has consistently been related to attention [14]. In experiment 2, fearful and neutral faces directed eye gaze at the infant and thus averted gaze from the object (dyadic context). We predicted that the effect of emotional expression on the amplitude of Nc should be reduced in experiment 2 compared with experiment 1. Further, when comparing both fearful-face conditions (between-subject), we expected an enhanced Nc amplitude for fearful faces in the triadic condition relative to the dyadic condition.

Methods

Participants

In experiment 1, 14 infants (7 females, average age 7 months and 14 days) were included in this study. Another 13 infants were tested but excluded from the sample because they failed to reach the minimum requirement of 10 artefact-free trials per condition for averaging. In experiment 2, 15 infants (9 females, average age 7 months and 15 days) were included and another 12 infants were tested but could not be included owing to a lack of usable trials. 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 fearful pictures were taken from both the actors. Their pupils 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 either to the left or 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. The same objects were presented in both conditions 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) and 19.5 cm high. In experiment 2, the same stimuli faces and objects were presented except that the pupils of the actors were not moved to the side but remained directed to the front at the infant.

Procedure

The procedure, electroencephalogram (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 fearful face, 100 with a neutral face). Stimuli were presented using the software ERTS (BeriSoft Corporation, Frankfurt, 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 was preceded by a small triangular fixation object presented in the middle of the screen for 500 ms. Then a stimulus picture was presented for 1000 ms. After the presentation of every stimulus, the screen was blank for a random period of 800–1000 ms. In sum, the interstimulus-interval (including the blank screen period and the fixation object) added up to 1200–1500 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.

Electroencephalogram recording and analyses

EEG was recorded continuously with Ag-AgCl electrodes from 19 scalp locations of the 10–20 system, referenced to the vertex (Cz). Data were amplified via a Twente Medical System's 32-channel REFA amplifier (Twente Medical Systems International, Enschede, The Netherlands). Horizontal and vertical electro-oculograms were recorded bipolarly. The sampling rate was set at 250 Hz. EEG data was rereferenced offline to the linked mastoids. The EEG recordings were segmented into epochs of waveform that was comprised of a 200 ms baseline featuring a triangular central fixation object and 1000 ms of one static image featuring a face and an object, as described above. For the elimination of electrical artifacts caused by eye and body movements, EEG data were rejected offline whenever the standard deviation within a 200-ms gliding window exceeded 80 μV at electro-oculogram electrodes or 50 μV at any other electrodes. Data were also visually edited offline for artifacts and matched with the infant's recorded behavior.

In experiment 1, each infant contributed 11–32 trials (mean of 17.5) to their average for the fearful face condition, and 11–35 trials (mean of 17.3) for the neutral condition. In experiment 2, each infant contributed 10–71 trials (mean of 20.0) to their average for the fearful face condition, and 10–67 trials (mean of 19.3) for the neutral condition.

For statistical analysis a time window was chosen around the amplitude peak of the effect from 400 to 600 ms after stimulus onset on central and right frontal channels and minimal amplitude was assessed. This region of interest (Fz, F4, FC4 and F8) was chosen on the basis of visual analysis of the data and is consistent with a right-hemispheric bias for face processing in earlier ERP studies investigating the Nc.

Results

Level of significance was P=0.05 for all statistical tests. For experiment 1, a paired-sample t-test was performed to assess differences between minimal amplitude of the Nc in response to fearful versus neutral faces looking at objects (triadic context). The t-test indicated a significant difference between the minimal amplitude of the Nc in the two conditions, $t(13)=-3.035$, $P=0.010$. As expected, the amplitude was larger for fearful faces [$M=-34.85\,\mu V$, standard deviation (SD) 16.93] than for neutral faces ($M=-25.36\,\mu V$, SD 11.28) (see Fig. 1a). No other significant effects were found. No difference between Nc amplitude for fearful versus neutral faces was found in experiment 2, $t(14)=-0.09$, $P=0.201$ (see Fig. 1b).

We further conducted an independent-sample t-test to compare minimal amplitude between the fearful face condition in experiment 1 (triadic context) and experiment 2 (dyadic context). A marginally significant difference was found, $t(27)=-2.046$, $P=0.051$. As expected, amplitude was larger for fearful faces looking at an object ($M=-34.85\,\mu V$, SD 16.93) than for fearful faces looking toward the infant and away from the object ($M=-24.28\,\mu V$, SD 10.30).

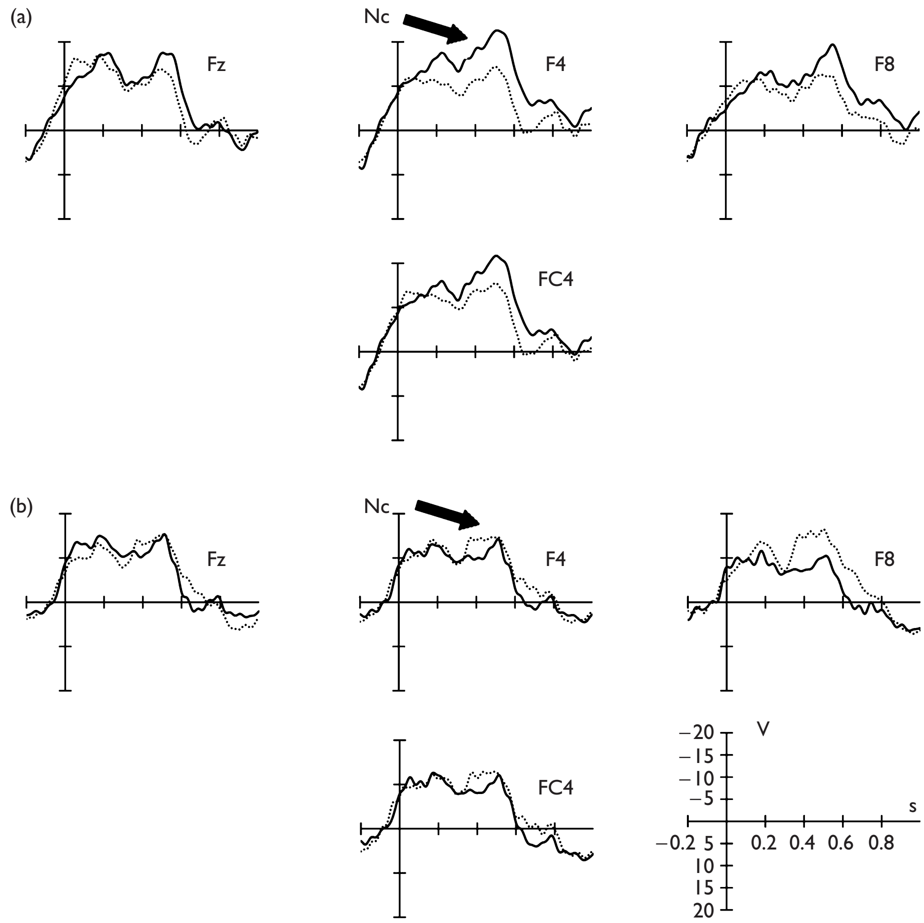

Fig. 1 ERPs on right and central frontal channels. (a) In the triadic context the Nc component is enhanced in the fearful face condition (solid line) compared with the neutral face condition (dotted line). (b) No difference is found in the dyadic context between fearful faces (solid line) and neutral faces (dotted line). Note that negative is up. ERPs, event related potentials; Nc, negative central.

Discussion

These data are the first to demonstrate infants' sensitivity to emotional expressions and gaze direction in a triadic person-object-person context. Seven-month-old infants' attention is increased by a fearful expression compared with a neutral face looking at an unfamiliar object. Importantly, this effect was only evident in a triadic context, that is, when the face directed eye gaze at a novel toy next to the face and not in a dyadic context in which the face looked toward the infant. This finding suggests that even 7-month-old infants use emotional expressions in triadic contexts to detect threat in the environment. Importantly, the same fearful expression had a differential effect on infants' brain responses depending on the social context. Only when the fearful face was directed at an object it elicited increased attention. This was reflected in an enhanced Nc component of the ERP, which is related to attentional processes [14].

In earlier research, the Nc component was sensitive to emotional expressions. An enhanced Nc was found for fearful faces relative to happy faces [15]; angry faces relative to happy [16] and fearful faces [17] and angry prosody relative to happy or neutral prosody [18]. Further, an enhanced Nc was found for angry faces with direct gaze compared with averted eye gaze [13]. Together these results indicate that the Nc reflects activation of an early neural threat detection system. Here, we demonstrate that the Nc component is also sensitive to the social context in which an emotional expression is perceived. By 7 months, infants discriminate between a fearful expression that is directed at an object and thereby possibly indicating threat; and a fearful expression directed at them, which is presumably more ambiguous [12].

The cortical source of the Nc component has been located in the prefrontal cortex and the anterior cingulate [19], which is implicated in the direction of attention [20]. Abnormal activation patterns in response to fearful facial affect were found in the anterior cingulate and the amygdala in patients with panic disorders [21]. The amygdala plays a crucial role in the processing of threat-related stimuli [22], and is sensitive to the direction of eye gaze in faces displaying fearful or angry affect [12]. A fearful face directing eye gaze at a novel stimulus may rapidly elicit activation in subcortical structures, which then modulate activation in cortical structures related to attentional processes [23]. Our findings suggest that this mechanism may come online very early in human ontogeny. Indeed, it has been argued that a subcortical face-processing pathway involving the amygdala exists already in early infancy, and that this pathway modulates responses of cortical areas to social stimuli [24].

The infant brain rapidly detects and processes potentially dangerous stimuli using social cues. From an evolutionary perspective, infants' susceptibility to social indicators of threat is a highly adaptive function. This ability enables humans to learn what in the environment is dangerous and should be avoided, without directly experiencing a dangerous situation. By the end of the first year, infants' behavior toward a novel object is affected by emotional expressions in combination with referential cues provided by an adult [25]. In particular, infants show attenuated and delayed exploration of novel objects when those objects are presented to them in the context of an adult's expression of negative emotion by the age of 11 months. We investigated a basic prerequisite to the ability to modulate behavior in response to social indicators of threat. Infants' attention is biased in the direction of potentially dangerous objects, which are cued by an adults' eye gaze and evaluated by his emotional facial expression. This may be the fundament on which social learning can develop and behavioral consequences in response to social indicators of threat can be expected. Future studies should further investigate the consequent processing of emotionally cued information.

Conclusion

Infants detect threat in the environment on the basis of facial expression and eye gaze. Infants' attention is enhanced when presented with a novel object in the context of a fearful face directing eye gaze at the object but not when eye gaze is averted from the object. This crucial mechanism enables infants to learn about potentially dangerous objects based on others' behavior and communicative signals without direct experience of threat. We conclude that infants are sensitive to threat related social cues even before they are able to adjust their behavior.

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