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Pupillary responses reveal infants' discrimination of facial emotions independent of conscious perception

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ABSTRACT

Sensitive responding to others' emotions is essential during social interactions among humans. There is evidence for the existence of subcortically mediated emotion discrimination processes that occur independent of conscious perception in adults. However, only recently work has begun to examine the development of automatic emotion processing systems during infancy. In particular, it is unclear whether emotional expressions impact infants' autonomic nervous system regardless of conscious perception. We examined this question by measuring pupillary responses while subliminally and supraliminally presenting 7-month-old infants with happy and fearful faces. Our results show greater pupil dilation, indexing enhanced autonomic arousal, in response to happy compared to fearful faces regardless of conscious perception. Our findings suggest that, early in ontogeny, emotion discrimination occurs independent of conscious perception and is associated with differential autonomic responses. This provides evidence for the view that automatic emotion processing systems are an early-developing building block of human social functioning.

1. Introduction

Emotional communication is an essential aspect of human social encounters (Frith, 2009). Perceiving emotional expressions in others triggers automatic physiological responses in the observer that are regulated by the autonomic nervous system such as changes in heart rate, skin conductance, and pupil dilation (Bradley, Miccoli, Escrig, & Lang, 2008; Ramachandra, Depalma, & Lisiewski, 2009). These responses reflect changes in activation or suppression of the sympathetic and parasympathetic parts of the autonomic nervous system and are thought to facilitate evolutionary adaptive responding to relevant information (Porges, 2003). Specifically, viewing facial emotional expressions has been shown to elicit changes in pupil dilation that occurred regardless of conscious perception of the face in adults (see Laeng, Sirois, & Gredeback, 2012, for review). Increased pupil dilation reflects greater activation of the sympathetic nervous system or a suppression of the parasympathetic nervous system, mediated by the locus coeruleus (Bradley et al., 2008; Laeng et al., 2012). The locus coeruleus has strong connections to other subcortical brain structures such as the amygdala (Van Bockstaele, Colago, & Valentino, 1998) and this is argued to support a close coupling between changes in pupil size and affective processing (Laeng et al., 2012). In particular, one can distinguish between phasic and tonic activation of the locus coeruleus; while the former characterizes responses to specific events, the latter is related to changes in task or a person's overall attentional state (Laeng et al., 2012).

Measuring pupillary responses to emotional stimuli has become an established method to examine subcortically mediated autonomic responses (sympathetic arousal) in adults (Bradley et al., 2008). Increased pupil dilation has typically been observed in response to emotionally arousing stimuli irrespective of valence (Bradley et al., 2008; Partala & Surakka, 2003). However, for facial expressions adults tend to show an increased pupil dilation in response to negative, especially fearful, compared to happy facial expressions (Laeng et al., 2013). The sympathetic arousal (pupil dilation) seen to fearful expressions has been argued to reflect a response that may prepare the body to flee (e.g., Porges, 2003). While most prior work has focused on consciously perceived emotions, changes in pupil size have also been observed in response to emotional stimuli that are not perceived consciously but were presented subliminally. As for supraliminal stimuli, an increase in pupil size in adults occurs in response to masked fearful facial expressions, which are not consciously perceived (Laeng et al., 2013). Along these lines, it has been shown that patients suffering from unilateral cortical blindness show a comparable increase in

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pupillary size to fearful stimuli presented in their blind or intact visual field (Tamietto et al., 2009). Taken together, prior work shows that fearful facial expressions automatically evoke increased pupil dilation in adults, indexing subcortically mediated greater sympathetic arousal.

Only recently research has begun to examine the developmental and brain origins of such automatic facial emotion processing systems during infancy. Prior behavioral and event-related brain potential (ERP) work has established face visibility thresholds in infants of various ages, serving as an important basis for the investigation of subliminal and supraliminal emotional face processing in infants (Gelskov & Kouider, 2010; Kouider et al., 2013). In a series of ERP studies (Jessen & Grossmann, 2014, 2015), it has been shown that 7-month-old infants discriminate between fearful and happy facial expressions regardless of whether facial emotional cues were presented subliminally or supraliminally. This suggests that, similar to what is known about adults (Smith, 2012), infants' facial emotion detection does not require conscious perception of visual emotional cues and is reflected in cortical processes measured by ERP. However, it is unclear whether processing others' emotional facial expressions is mediated by subcortical processes and impacts infants' autonomic responses, especially pupil dilation, independent of conscious perception.

Pupillometry has received increased attention in developmental research concerned with the early development of social perception and cognition in recent years, because it allows for the noninvasive investigation of autonomic responses, providing an important window into the social mind of preverbal infants (Hepach, Vaish, & Tomasello, 2012; Jackson & Sirois, 2009). With respect to emotion perception during infancy, using audio-visual displays, 6- and 12-month-old infants have been found to show largest pupil dilation in response to other infants in distress when compared to a neutral condition, but pupil dilation was also increased in response to other infants expressing happiness (Geangu, Hauf, Bhardwaj, & Bentz, 2011). Infant pupillary responses to adult emotional facial expressions appear to depend on several contextual factors. For example, 14-month-old infants' pupil dilation responses to fearful facial expressions depend on whether they view their parent or a stranger and also on whether their primary caregiver is their mother or their father (Gredeback, Eriksson, Schmitow, Laeng, & Stenberg, 2012). Furthermore, 14-month-old infants, but not 10-month-old infants, show increased pupil dilation when the emotion expressed by an adult mismatched the action carried out by the adult (Hepach & Westermann, 2013). This suggests that pupil dilation is a sensitive measure of infants' emerging sensitivity to emotions in others and that, at least in older infants, contextual factors contribute to pupil dilation responses to emotions. Critically, it remains to be seen how younger infants respond to fearful and happy facial expressions displayed by adults and whether pupil dilation to emotional facial expressions occurs independent of conscious perception.

In the current study, we therefore investigated pupillary responses in 7-month-old infants to fearful and happy facial expressions presented subliminally and supraliminally. This age group was chosen because 7-month-old infants have been shown to be able to discriminate between fearful and happy facial expressions (Peltola, Leppänen, Mäki, & Hietanen, 2009). Based on prior ERP work (Jessen & Grossmann, 2014, 2015), we hypothesized that infants are able to discriminate between emotional facial expressions regardless of conscious perception. More specifically, we examined whether infants' pupil dilation will be greater to fearful when compared to happy facial expressions, as previously shown in adults (Laeng et al., 2013). While our main analysis was focused on pupil dilation, in addition, we examined infants' looking patterns using eyetracking as this has also been shown to vary as a function of others' emotional expression (Hunnius, de Wit, Vrins, & von Hofsten, 2011). We hypothesized that looking patterns (face scanning) in infants will provide additional evidence for emotion discrimination independent of conscious perception. Furthermore, measuring pupil dilation and looking patterns allowed us to examine the relationship between the two measures.

2. Methods

2.1. Participants

Thirty infants were invited to participate in the study. The infants were seven months of age (mean: 205 days, range 196–225 days, 16 female). For one infant, no eye tracking data could be obtained, as the infant was too fussy. Infants were included in the analysis of pupil size and the analysis of fixation duration according to different inclusion criteria (see below). Twenty infants (10 female, mean age: 204 days) were included in the analysis of pupil size, and 22 infants (11 female, mean age: 204 days) were included in the analysis of fixation duration.

All infants were born full-term (38–42 weeks gestational age), had a birth weight of at least 2800 g and no known visual impairments. The parents gave written informed consent. The study was approved by the local ethics committee, and conducted according to the declaration of Helsinki.

2.2. Stimuli

The basic stimulus material consisted of happy, fearful, and neutral facial expressions portrayed by six young actresses from the FACES database (age 19–30, ID-numbers 54, 63, 85, 90, 115, and 173, see Ebner, Riediger, and Lindenberger, 2010). All emotional faces had been recognized with an accuracy of at least 90% by a group of young adults ($N = 52$, age 20–31 years, see Ebner et al., 2010). These photographs were cropped so that only the face and a minimum of hair was visible in an oval shape. To compare luminance between the conditions, pictures were converted to grayscale (while preserving luminance), the sum of all pixels was computed, and these values were entered into an ANOVA. Stimuli from the different emotions did not differ in luminance ($p = .28$). Additionally, we created scrambled masks from neutral facial expressions that were presented after each subliminal stimulus. The faces were presented with a height of 21.5 cm and a width of 16 cm.

One feature with respect to which happy and fearful faces might differ is the visibility of teeth, since happy faces are more likely to be characterized by an open mouth (laughing). However, this is unlikely to account for differences observed across emotions in the current study because teeth were not only visible in the happy facial expressions but also in four out of the six fearful facial expressions presented.

To keep the infants' attention focused on the screen, we presented short video clips containing bubbles moving in front of a blue background after each trial (Hepach et al., 2012).

Besides the stimuli included in the analyses, four additional types of stimuli were presented but not analyzed for the present manuscript. In these pictures, only the sclera of the eyes of happy and fearful facial expressions was visible, either showing a white sclera with a black pupil or a black sclera with a white pupil.

2.3. Design

Happy and fearful facial expressions were presented either supra- or subliminally, resulting in a 2×2 design with the factors Emotion (happy, fear) and Presentation Condition (supraliminal, subliminal). Each trial started with a single bubble that was