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Contrast reversal of the eyes impairs infants' face processing: A near-infrared spectroscopic study

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ABSTRACT

Human can easily detect other's eyes and gaze from early in life. Such sensitivity is supported by the contrast polarity of human eyes, which have a white sclera contrasting with the darker colored iris (Kobayashi & Kohshima, (1997). *Nature*, *387*, 767–768; Kobayashi & Kohshima, (2001). *Journal of Human Evolution*, *40*, 419–435). Recent studies suggest that the contrast polarity around the eyes plays an important role in infants' face processing. Newborns preferred upright face images to inverted ones in contrast-preserved faces, but not in contrast-reversed faces (Farroni et al., (2005). *Proceedings of National Academy of Sciences of the United States of America*, *102*, p. 17245–17250). Seven- to 8-month-old infants failed to discriminate between faces when the contrast polarity of eyes was reversed (Otsuka et al., (2013). *Journal of Experimental Child Psychology*, *115*, 598–606). Neuroimaging study with adults revealed that full-negative faces induced less activation in the right fusiform gyrus than either full-positive faces or negative faces with contrast-preserved eyes (Gilad et al., (2009). *Proceedings of National Academy of Sciences of the United States of America*, *106*, p. 5353–5358). In the present study, we investigated whether contrast-reversed eyes diminish infants' brain activity related to face processing. We measured hemodynamic responses in the bilateral temporal area of 5- to 6-month-old infants. Their hemodynamic responses to faces with positive eyes and those with negative eyes were compared against the baseline activation during the presentation of object images. We found that the presentation of faces with positive eyes increased the concentration of oxy-Hb in the right temporal area and those of total-Hb in the bilateral temporal areas. No such change occurred for faces with negative eyes. Our results suggest the importance of contrast polarity of the eyes in the face-selective neural responses from early development.

1. Introduction

The eyes convey socially important information such as gaze that informs us about the observer's direction of attention (for review, Itier & Batty, 2009). From immediately after birth, human infants can detect other's eyes and gaze. Newborns prefer looking at faces with eyes conveying a communicative signal, such as open eyes rather than closed eyes (Batki, Baron-cohen, & Wheelwright, 2000) and mutual gaze rather than averted gaze (Farroni, Csibra, Simion, & Johnson, 2002). The ability to detect other's eyes and gaze are necessary to the later development of gaze following (Farroni, Johnson, Brockbank, & Simion, 2000; Farroni, Johnson, & Csibra, 2004) and joint attention (Emery, 2000).

Our sensitivity to other's gaze is supported by a morphological feature of the human eyes in which a widely exposed white sclera contrasts with the darker colored iris (Tomasello, Hare, Lehmann, & Call, 2007). This contrast polarity relationship in the eyes is unique to human among primates (Kobayashi & Kohshima, 1997, 2001). Irrespective of variations in the color of skin, hair, and iris, the color of sclera is commonly white and lighter than the iris and pupil. The contrast polarity relationship of the eyes is one of the fundamental features of human faces and works as a visual cue for infants to recognize a human faces.

Recent studies suggest that contrast polarity around the eyes plays an important role in infants face processing. Farroni et al. (2005)

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reported newborns' preference for canonical face images over inverted ones can be observed only in contrast-preserved faces, but not in the contrast-negative or bottom-lit faces. They examined the upright face preference of newborns using a facial photograph and the schematic face-like pattern consisting of three black squares (corresponding to eyes and mouth) surrounded by a white head-shaped surface. The upright face preference disappeared when contrast polarity reversed versions of these images were used. Importantly, however, the upright preference reappeared for the contrast reversed schematic face when the smaller black squares were inserted into the white squares, making the contrast polarity consistent with darker iris of eye. Furthermore, we have examined the role of contrast polarity around the eyes on the face recognition of 7- to 8-month-olds by independently manipulating the contrast polarity of the eyes and the rest of the face (Otsuka et al., 2013). We found that 7- to 8-month-old infants discriminated between faces if the contrast polarity of eyes was preserved regardless of the contrast polarity of the rest of the face.

In accordance with impaired face recognition findings in infants, recent neuroimaging studies with adults have reported that brain activity related to face processing also modulates for faces with contrast-negative eyes. Using functional MRI, Gilad, Meng, and Sinha (2009) reported that contrast-negative faces induced less activation in the right fusiform gyrus than either full-positive faces or negative faces with contrast-positive eyes. Gilad et al. demonstrated that contrast negation around the eyes is critical for attenuated face recognition both behaviorally and neurally. Furthermore, ERP study with adults (Itier, Alain, Sedore, & McIntosh, 2007) have reported that the contrast-negative faces induced longer latency and larger amplitude of the N170 than the positive faces. Because the main contributor of the N170 is likely the STS region (Itier & Taylor, 2004; Watanabe, Kakigi, & Puce, 2003), such differential N170 would indicate STS involvement in the processing of contrast-negative eyes. To examine the brain areas involved in eye or gaze processing, most neuroimaging studies used face images rather than isolated-eye stimuli (Itier & Batty, 2009) and reported activation in the occipital temporal region, including STS (Allison, Puce, & McCarthy, 2000; Hoffman & Haxby, 2000).

In this study, we investigated whether contrast-negative eyes diminish infants brain activity specific for face processing. Previous studies have shown that the eye region in the face image modulates infants' neural response to faces. Farroni et al. (2004) demonstrated that 4-month-old infants showed differential ERP response known to be sensitive to faces (N170) in adults to direct and averted gaze irrespective of head orientation. For faces with direct gaze, infants showed a greater response of "the infant N170" compared to faces with averted gaze. Since infants' sensitivity to eyes emerges by four months of age and our previous near-infrared spectroscopy (NIRS) study reported face specific brain activity in 5-month-olds (Kobayashi et al., 2011; Kobayashi, Otsuka, Kanazawa, Yamaguchi, & Kakigi, 2012; Nakato et al., 2009; Otsuka et al., 2007), we examined the brain activity related to face processing in 5- to 6-month olds. We manipulated the contrast polarity of the eyes and created faces with contrast-positive eyes and those with contrast-negative eyes. Using NIRS, we measured infants' hemodynamic change in the bilateral temporal areas and compared their hemodynamic response between faces with contrast-positive eyes and faces with contrast-negative eyes.

2. Methods

2.1. Participants

The participants were 13 healthy infants aged 5–6 months (7 boys and 6 girls, mean age = 168 d, ranging from 141 to 188 d). An additional two infants were excluded from the final analysis due to an insufficient number of available trials (less than three trials for either the upright or inverted condition), or motion artifacts. This study was approved by the Ethical Committee of Chuo University and that of the National Institute for Physiological Sciences. Written informed consent was obtained from the parents of the infant participants. The experiments were conducted according to the Declaration of Helsinki.

2.2. Stimuli and design

The sequence of stimuli presentation consisted of a test period and a baseline period. The stimuli for the test period were dynamic face images consisting of closed eyes and open eyes images shown in alternation. The stimuli were created from facial photographs of six Japanese females each with eyes opened and eyes closed. From each of the six original facial images with opened eyes, we produced two variants (Fig. 1): images with contrast-preserved eyes (faces with positive eyes) and images with contrast-reversed eyes (faces with negative eyes). This was done by manipulating the eye region (including sclera, iris and pupil) under gray-scale, and then combining it with the rest of the facial regions that remained in full-color. After transformation of the original contrast-preserved eye region, it was contrast-reversed to produce a negative eye region. Then, we adjusted the luminance of the eye regions so that the mean luminance was matched between positive and negative versions of the eye regions. The sizes of the stimuli were approximately $14.3^{\circ} \times 19.2^{\circ}$ in visual angle. In each trial, faces of four out of the six female faces

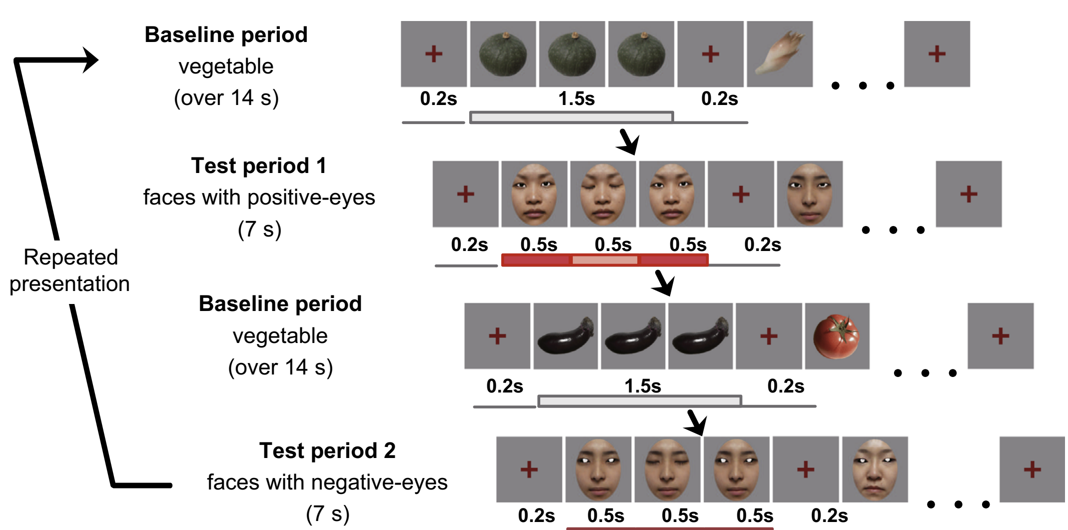

Fig. 1. Experimental procedure. In each trial, the baseline period consisted of stimuli of images of six vegetables, and its duration was at least 14 s. The test period consisted of two conditions presenting faces: the faces with-positive eye condition and the faces with negative-eye condition. The duration of the test period was fixed for 7 s. The presentation order of test periods 1 and 2 were exchanged alternately for each infant.