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Neural correlates of own- and other-race face recognition in children: A functional near-infrared spectroscopy study☆

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ABSTRACT

The present study used the functional Near-infrared Spectroscopy (fNIRS) methodology to investigate the neural correlates of elementary school children's own- and other-race face processing. An old-new paradigm was used to assess children's recognition ability of own- and other-race faces. FNIRS data revealed that other-race faces elicited significantly greater [oxy-Hb] changes than own-race faces in the right middle frontal gyrus and inferior frontal gyrus regions (BA9) and the left cuneus (BA18). With increased age, the [oxy-Hb] activity differences between own- and other-race faces, or the neural other-race effect (NORE), underwent significant changes in these two cortical areas: at younger ages, the neural response to the other-race faces was modestly greater than that to the own-race faces, but with increased age, the neural response to the own-race faces became increasingly greater than that to the other-race faces. Moreover, these areas had strong regional functional connectivity with a swath of the cortical regions in terms of the neural other-race effect that also changed with increased age. We also found significant and positive correlations between the behavioral other-race effect (reaction time) and the neural other-race effect in the right middle frontal gyrus and inferior frontal gyrus regions (BA9). These results taken together suggest that children, like adults, devote different amounts of neural resources to processing own- and other-race faces, but the size and direction of the neural other-race effect and associated functional regional connectivity change with increased age.

Introduction

Human adults are experts at processing faces. We are able to discriminate very subtle differences between two faces (e.g., Ge et al., 2009), and readily recognize thousands of faces, many of which have not even been seen for decades (e.g., Bahrick et al., 1975). Nevertheless, our face expertise is only limited to the category of faces with which we have extensive experience. One prime example of such limitation is the so-called other-race effect (ORE), whereby we have greater recognition memory for own-race faces than that for other-race faces due to our extensive experience with individuals from our own race, and limited or no experience with individuals from other races. This effect is robust in adults and has been found with the use of various methodologies and with adults from different racial backgrounds (Hancock and Rhodes, 2008; Hayward et al., 2008; Mondloch et al., 2010a; Pezdek et al., 2003; Rhodes et al., 2006; Sangrigoli et al., 2005; Walker and Tanaka, 2003; for reviews, see Hugenberg et al., 2010; Meissner and Brigham, 2001).

Developmental research has revealed that the other-race effect emerges in infancy (for a review, see Lee et al., 2011, and Anzures et al., 2013). By three months of age, infants who only have experience with own-race individuals prefer to look at own-race faces over other-race faces (Bar-Haim et al., 2006; Kelly et al., 2005). At 6 months, infants begin to show a recognition advantage for own-race faces, and by 8–9 months of age this other-race effect becomes more pronounced (Anzures et al., 2010; Ferguson et al., 2009; Hayden et al., 2007, 2009; Kelly et al., 2007, 2009; Sangrigoli and de Schonen, 2004a). With further experience with own-race faces and continued lack of experience with other-race faces, children have also been found to have an own-race face recognition advantage with increased age, with the other-race effect less reliable at younger ages and becoming more robust with increased age (Anzures et al., in press; Chance et al., 1982; Feinman and Entwisle, 1976; Goodman et al., 2007; Pezdek et al., 2003; Sangrigoli and de Schonen, 2004b; Walker and Hewstone, 2006). The existing behavioral findings from infants, children, and adults taken together strongly support the proposal (Scott et al., 2007) that our

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asymmetrical experience with different types of faces (e.g., own- versus other-race faces or own- versus other- species faces) affects the development of face processing expertise in a profound manner.

In contrast to the large number of behavioral studies, limited event-related potential (ERP) and functional magnetic resonance (fMRI) studies have examined the neural mechanisms underlying the other-race effect of face processing in adults (for a review, see Ito and Bartholow, 2009). Using the ERP technique, which has exquisite temporal resolution but poor spatial resolution, recent studies (Caharel et al., 2011; Caldara et al., 2004; Ito and Urland, 2005) have revealed a number of marked electrophysiological response differences as early as 170 ms post stimulus onset when adults view own- and other-race faces. Using the fMRI technique, which has high spatial resolution but poor temporal resolution, researchers have also found that adults show blood hemoglobin response differences between own- and other-race faces in various cortical and subcortical regions such as the amygdala, bilateral fusiform gyrus (e.g., the Fusiform Face Area or FFA: Golby et al., 2001; Kanwisher and Yovel, 2006; Natu et al., 2010), middle occipital gyrus (e.g., the occipital face area or OFA: Kanwisher and Yovel, 2006; Natu et al., 2010), and bilateral prefrontal cortical regions such as the inferior frontal gyrus, and middle frontal gyrus (Cunningham et al., 2004; Feng et al., 2011; Kim et al., 2006; Lieberman et al., 2005; Van Bavel et al., 2008). These adult findings thus reveal a neural other-race effect (NORE) paralleling the behavioral other-race effect, suggesting that adults' asymmetrical experience with own- and other-race faces have a direct impact not only on their behavior but also on neural responses.

However, the developmental origin of the neural other-race effect is entirely unknown. Except for one ERP study demonstrating infants to respond differentially to own- and other-race faces (Balas et al., 2011), to the best of our knowledge, no neuroimaging study to date has investigated the neural correlates of own- and other-race face processing in children. Neuroimaging research on the development of the other-race effect will bridge the significant gap in our knowledge about how the neural other-race effect emerges and develops in childhood. This knowledge will thus bring us closer to a comprehensive understanding of the development of own- and other-race face processing from infancy to adulthood at both behavioral and neural levels. Further and more broadly, such research will elucidate how experience influences the developing brain systems to acquire such important visual expertise as face processing abilities.

To bridge this significant gap in the literature, we conducted the present study with Chinese children between the ages of 7 and 13 years who had been exposed nearly exclusively to own-race faces and had no direct contact with other-race individuals. We used an old-new paradigm to assess children's recognition ability of own- and other-race faces. Children were first asked to remember a set of Chinese faces in the Chinese Face Recognition task or Caucasian faces in the Caucasian Face Recognition task. After familiarization, they were shown the studied “old” (target) faces mixed with an equal number of new, unstudied (foil) Chinese or Caucasian faces. They judged which face was old and which was new.

We used the functional Near-infrared Spectroscopy (fNIRS) methodology to investigate the neural correlates of children's own- and other-race processing. Although NIRS does not have as high of a spatial resolution as the MRI methodology and only measures cortical hemodynamic activities a few centimeters deep in the cortex, it has several advantages, especially for the purpose of the present study. First, a NIRS machine is quiet and highly mobile and does not require a specially controlled laboratory environment. Thus, experiments can take place in an environment that is not as foreign, noisy, dark, or claustrophobic as that of an MRI machine (Suda et al., 2010). Second, NIRS has much higher temporal resolution than MRI in a typical fMRI study, at 10 Hz (although recent advances in fMRI protocols may soon mitigate this advantage). This temporal resolution makes it possible to obtain a recording of the actual time course of one hemodynamic response epoch in response to a specific cognitive task in a specific trial when a slow event-related design is used. Third, unlike an fMRI experiment where participants must lie down on a gantry with their head firmly restrained in a head coil, participants in an fNIRS experiment can sit up in a normal posture with less head restraining due to NIRS's relative higher tolerance for motion. Fourth, due to the small operating costs associated with NIRS, it is possible to run fNIRS study with a large sample of participants of a wide age span. Thus, fNIRS is particularly well suited for developmental studies involving children.

Based on the existing adult findings (e.g., Feng et al., 2011), we hypothesized that own- and other-race faces would engender different levels of neural responses. The activation differences should be observed in areas of the posterior occipital cortex such as the middle occipital gyrus (MOG) and areas of the prefrontal cortex such as the inferior frontal gyrus (IFG) and the middle frontal gyrus (MFG). These areas have been implicated in existing adult fMRI studies of face processing in general (e.g., Esterman and Yantis, 2010; Li et al., 2010; Maurer et al., 2007) and own- and other-race face processing in specific (e.g., Cunningham et al., 2004; Feng et al., 2011; Lieberman et al., 2005). The prefrontal areas are known to be part of the extended face processing network in adults (Haxby et al., 2000). We also hypothesized that with increased age, children's differential neural responses to own- and other-race faces would become increasingly greater in both occipital and prefrontal regions. Further, children's behavioral responses to own- and other-race faces would be significantly correlated with their differential neural responses to the two types of faces.

Methods

Participants

Seventy-two Chinese children with no history of neurological or psychiatric disorders took part in this study (Mean age = 9.98, SD = 1.79, range from 7.13 to 13.50 years; 40 boys, 32 girls). All children were Han Chinese living in a metropolitan city with 99.99% of the population being Han Chinese. They all had normal or corrected to normal vision. None of them reported having direct contact with any other-race individuals. The research was approved by the university ethics committee. Informed consent was obtained from all parents prior to beginning the study and oral assent was obtained from all child participants. After the experiment, children were debriefed and given a prize (e.g., toys).

Stimuli

Black-and-white photos of 20 Chinese and 20 Caucasian young female adults with a resolution of 450 × 600 pixels were used in the present study. All faces were upright, frontal with neutral emotional expressions.

Procedure

Children were seen individually. They were seated in front of a computer screen at a distance of 60 cm. They were instructed to complete two within-subjects tasks: the Chinese face task and the Caucasian face task. Each task included two phases: the learning phase and the testing phase (Fig. 1). During the learning phase, children were shown 10 target faces (Chinese or Caucasian) in a randomized order and asked to remember all of the faces. The faces were shown three times. During each trial of the learning phase, each face was presented for 3000 ms with intervals of a 2000 ms central fixation point between two adjacent face photos. During the testing phase, the 10 target face photos that were used in the learning phase were intermixed randomly with another 10 foil faces (Chinese or Caucasian). The testing target and foil faces were shown individually. Each face was displayed for 3000 ms after a 2000 ms central fixation point, followed by another fixation point lasting 8000 ms in order to make sure the signal activated by the last trial returned to baseline. Children were asked to press either ‘1’ or ‘2’ on the keyboard to indicate whether the face presently seen was an “old” target face (one learned during the learning phase) or a