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

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ARTICLE INFO

Article history:
Accepted 15 July 2013
Available online xxx

Keywords:
fNIRS
Face processing
Face recognition
The other-race effect
Own-race or other-race face recognition
Functional connectivity
Children
Development

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.

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1053-8119/$ – see front matter © 2013 Published by Elsevier Inc.
http://dx.doi.org/10.1016/j.neuroimage.2013.07.051

Please cite this article as: Ding, X.P., et al., Neural correlates of own- and other-race face recognition in children: A functional near-infrared spectroscopy study, Neuroimage (2013), http://dx.doi.org/10.1016/j.neuroimage.2013.07.051
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., 2011). These adult findings 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)

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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 “new” foil face. The key assignment was counterbalanced between children. The order of Chinese task or Caucasian task was counterbalanced between children. During the testing phase, we used the NIRS imager to measure children's neural responses to own- and other-race faces.

**fNIRS data acquisition**

A 48 channels continuous wave system (ETG-4000, Hitachi Medical Co., Japan) was used in the present study (although we only used 46 channels). The probes of the NIRS machine were fixed using two 6 × 6 cm² rubber shells over the frontal areas and one 6 × 12 cm² rubber shell over the occipital areas. The shells were covered with a nylon-net to keep them attached to the head. The two shells of 9 probes, consisting of a pair of 3 × 3 arrays with five light emitters and four detectors, and one shell of 15 probes, consisting of a 5 × 3 arrays with eight light emitters and seven detectors, were capable of measuring the relative concentrations of hemoglobin at 46 points (See Fig. 2).
The lowest probes of the frontal areas were positioned along the Fp1–Fp2 line while the lowest probes of the occipital areas were positioned along the O1–O2 line in accordance with the international 10–20 system for electroencephalography. The placements of the probes in the dorsal bilateral frontal areas and occipital areas were based on our hypotheses derived from the existing related fMRI studies. The inter-optode distance was 30 mm, which allowed for measuring hemodynamic activities approximately 15–25 mm beneath the scalp. Optical data from individual channels were collected at 2 different wavelengths (695 and 830 nm) and analyzed using the modified Beer–Lambert Law for a highly scattering medium (Cope and Delpy, 1988). Changes in oxygenated ([oxy-Hb]) and deoxygenated ([deoxy-Hb]) signals were calculated in units of millimolar–millimeter (mM * mm) (Maki et al., 1995). The sampling rate was set to 10 Hz.

We used a 3D-magnetic space digitizer (EZT-DM401, Hitachi Medical Corporation, Japan) to measure the exact spatial location of each optode in relation to the veridical landmarks of a participant's head (i.e., nasion, inion, Cz, the pre auricular points anterior to the left and right ears). We used the probabilistic registration method (Singh et al., 2005) to obtain estimation of each channel’s corresponding location in the Montreal Neurological Institute (MNI) space.

**fNIRS data analysis**

We analyzed the [oxy-Hb] and [deoxy-Hb] signals. For each participant, we segmented event epochs from the time course data. Each event epoch consisted of a 2 s period prior to stimulus onset, 3 s of the stimulus period, 5 s of the recovery period, and a 3 s post-stimulus period. However, we found the [deoxy-Hb] signals to be noisy and unreliable as reported by other researchers previously (Homae et al., 2007). Thus, we focused our data analyses only on the [oxy-Hb] data here.

**General linear model (GLM) analysis**

To explore the spatial correlates underlying the different trial types, the [oxy-Hb] data were analyzed using NIRS-SPM (Jang et al., 2009; Tak et al., 2011; Ye et al., 2009). For each participant, data were preprocessed to remove sources of noise and artifact (such as movement and heart rate) using a hemodynamic response function (hrf) filter and a wavelet-MDL (minimum description length) detrending algorithm. Then, a general linear model incorporating task effects, a mean, and a linear trend were used to compute parameter estimates and t-contrasts for the comparison (own-race faces recognition versus other-race faces recognition). Thus we used this channel as the seed channel to perform NIRS channel positions on an estimated MNI space were obtained from a 3D digitizer using algorithms by Singh et al. (2005).

**Regional functional connectivity analysis results based on the GLM data from individual children**

To further understand whether individual children's neural responsivity in one channel correlated with their responsivity in another, we first identified the channel that revealed significant differences between the own- and other-race face conditions based on the GLM analyses. Then, we use this channel as the seed channel to perform Pearson correlations between children's beta values derived from the GLM analyses in the seed channel with their beta values in all other channels.

**Correlations between behavior and NIRS GLM data**

To understand whether children's neural responsivity correlated with their behavioral responses, we calculated Pearson correlations between children's behavioral measures (the correct reaction time and accuracy in own-race and other-race faces conditions) and their beta values in all channels.

**Results**

**Behavior results**

Preliminary results revealed no significant effects for gender. Thus, the results for this factor were collapsed for all subsequent analyses. The descriptive results of face recognition performance are shown in Table 1.

Three analyses of variance were first conducted to determine if there was an overall preference to one face type over the other. A repeated measures 2 (stimulus race: own vs. other race) × 1 (age in years: continuous) ANOVA was performed with stimulus race (own-race face or other-race face) as a within-subjects variable, participant age as a continuous variable, and accuracy and reaction time in milliseconds as the dependent variables. For the accuracy, only the main effect of age was significant, $F(1,70) = 5.93, p < .05, \eta^2 = .08$; with increased age, children's accuracy improved significantly for both own- and other-face conditions. For the correct reaction time, only the main effect of age was significant, $F(1,70) = 4.89, p < .05, \eta^2 = .07$; with increased age, children's reaction time decreased significantly. However, no significant differences were found between own- and other-face races ($p > .05$).
The beta value of the hemodynamic activities between own-race minus other-race face conditions (corrected by FDR, \( p < .05 \)).

<table>
<thead>
<tr>
<th>Ch</th>
<th>Estimated MNI</th>
<th>Brain area</th>
<th>Maximum probability</th>
<th>Mean beta value of own-race face condition</th>
<th>Mean beta value of other-race face condition</th>
<th>F-test Oxy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ch19</td>
<td>55</td>
<td>Right MFG/IFG (BA9)</td>
<td>0.50</td>
<td>.02</td>
<td>.04</td>
<td>7.53**</td>
</tr>
<tr>
<td>Ch40</td>
<td>-4</td>
<td>Left cuneus (BA18)</td>
<td>0.49</td>
<td>.03</td>
<td>.06</td>
<td>6.68*</td>
</tr>
</tbody>
</table>

Note:* refers to \( p < .05 \), ** refers to \( p < .01 \) (after corrected by FDR).
other-race face recognition; continuous) as independent variables. No significant effects were found.

We performed analyses of variance on the NORE (the differences in the [oxy-Hb] activity between own- and other-race faces in Ch19) as the dependent variable, with age (continuous) and the behavioral ORE in reaction time (i.e., the difference in reaction time between other- and own-race face recognition; continuous) as independent variables. The age effects were significant ($F(1,71) = 4.26, p < .05, \eta^2 = .06$): with increased age, the NORE became bigger (part $r = .31, p = .01$). The behavioral ORE was also significant ($F(1,71) = 7.59, p < .01, \eta^2 = .10$): the greater the children's behavioral ORE in reaction time, the bigger the NORE (part $r = .23, p = .04$).

Discussion

The present study, for the first time, examined the neural correlates of own- and other-race face processing in children between 7 and 13 years of age with the use of fNIRS methodology. We found that (1) behaviorally, children generally did not show significant differences in response accuracy and reaction time when they recognized own- and other-race faces but their processing performance increased with age; (2) a neural other-race effect (NORE) was found in Channel 19 (BA9, right MFG/IFG) and Channel 40 (BA18, left cuneus), and this effect changed with age. More specifically, the [oxy-Hb] changes were modestly greater to other-race faces, than own-race faces at younger ages, whereas the [oxy-Hb] changes were modestly significantly greater to own-race faces than other-race faces in these two cortical areas.
Thus, it is possible that these areas are crucial for children to process faces in general and less familiar face categories in particular. However, no existing adult fMRI studies have found that there was face-race related differential activation in the left cuneus. There was only one study which showed that the right middle fusiform gyrus in a mild cognitively impaired adult group had a higher positive linear correlation with the left cuneus than the healthy control group in own-race face matching tasks (Bokde et al., 2006). The researchers suggested that these increases in functional connectivity might be a compensatory process of processing perceptual features of the faces. It is possible that the presenting findings with the left cuneus might also be related to children's reliance on processing face features more generally and the features of other-race faces in particular given the immaturity of their face processing expertise relative to that of adults (Mondloch et al., 2010b).

Interestingly, the NORE appeared to undergo an age-related shift: at the younger ages, other-race faces elicited modestly greater [oxy-Hb] changes than own-race faces in these two areas, suggesting that young children recruited greater neural resources for processing other-race faces than own-race faces, resulting in a marginally negative neural other-race effect. However, with increased age, own-race faces increasingly elicited modestly greater [oxy-Hb] changes than other-race faces, resulting in a marginally positive neural other-race effect. The cognitive mechanisms associated with this age related change are unclear. Given the existing adult fMRI studies regarding the IFG and MFG in terms of face familiarity (e.g. Feng et al., 2011; Ito and Bartholow, 2009; Kim et al., 2006), it is possible that children of different ages had different processing strategies when dealing with faces of familiar and unfamiliar categories. Younger children might have a novelty preference and thus focus on the novel other-race face category more than the more familiar own-race face category. In contrast, older children might have a familiarity preference and thus devote more neural resources to own-race faces, a strategy that is adaptive in children's everyday life as they hardly ever encounter

Fig. 4. Correlations of beta values in Channels 19/40 with other brain areas with all children's data combined.
Fig. 5. Correlations of beta values in Channels 19/40 with other brain areas in different age groups.
behavioral performance. As a result, our task failed to reveal a behavioral other-race effect, a highly robust phenomenon found mostly with adults. Thus, more sensitive behavioral paradigms are needed so as to obtain a behavioral other-race effect, which in turn might have better sensitivities to reveal the neural other-race effect than the present study. Furthermore, in the present study, we only recruited children 7–13 years of age as participants, whereas the effect has been reported in preschoolers and even infants. Future fNIRS studies need to extend to these younger age groups so as to obtain a comprehensive picture of the development of the other-race effect in behavior and in neural responsivity as the fNIRS methodology has been shown to be well suited for studying face processing in even very young infants (Kobayashi et al., 2012; Nakato et al., 2009; Otsuka et al., 2007). Last but not least, future studies need to assess the accuracy and validity of using the probabilistic registration method (Singh et al., 2005) to estimate child MNI coordinates and thus the exact MNI locations of the optical channels reported here need to be interpreted with caution.

Summary

The present study for the first time used the functional near-infrared Spectroscopy (fNIRS) methodology to investigate the neural correlates of children’s own- and other-race processing. An old-new paradigm was used to assess children’s recognition ability of own- and other-race faces. The results showed that children generally did not show significant differences in response accuracy and reaction time when they recognized own- and other-faces but their processing performance increased with age. However, in terms of neural responses, other-race faces elicited significantly greater [oxy-Hb] changes than own-race faces in Ch19 (BA9, right MFG/IFG) and Channel 40 (BA18, left cuneus). Further, with increased age, the [oxy-Hb] activity differences between own- and other-race faces, or the NORE, underwent significant changes in these two cortical areas: at younger ages, the neural response to the other-race faces was greater than that to the own-race faces, but with increased age, the neural response to the own-race faces became increasing greater than that to the other-race faces. Moreover, Channels 19/40 showed strong regional functional connectivity with a large swath of the cortical regions in terms of the neural other-race effect and these regional functional connectivities also went significant changes with increased age. We also found significant and positive correlations between the behavioral ORE (reaction time) and the NORE in Channel 19. Our findings 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 change with increased age.

Uncited reference

Morita et al., 2008

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.neuroimage.2013.07.051.

References


