

Atypical N170 lateralization of face and word recognition in Chinese children with autism spectrum disorder

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ABSTRACT

Atypical brain lateralization patterns in processing both human faces (reduced right lateralization) and alphabetic languages (reduced left lateralization) have been found in autism spectrum disorder (ASD). Yet, whether Chinese children with ASD show similar atypical brain lateralization patterns in processing faces and language is largely unknown. The aim of the present study was to examine this issue with N170, an event-related potential (ERP) component responsible for faces and visual words. Twenty Chinese children with ASD and 18 typically developing children participated in the study. ERPs were recorded while participants were presented with Chinese characters and faces. Results showed a significant right-lateralization of N170 for control children in processing both faces and characters, whereas there was no lateralization of N170 for children with ASD, either in processing faces or characters. The results suggest that Chinese children with ASD exhibited atypical lateralization in processing both faces and written words. The reduced right lateralization for processing faces in Chinese children with ASD compared with the control group was similar to the lateralization deficits demonstrated in western studies. However, the reduced right lateralization for processing Chinese characters in ASD was different from the deficit pattern of lateralization for processing alphabetic languages.

1. Introduction

Autism spectrum disorder (ASD) is a set of developmental disabilities diagnosed in childhood and has a significant impact throughout the entire life (Roberts et al., 2008). The symptoms of ASD involve social and communicative impairments, restricted interests, and stereotyped behaviors (American Psychiatric Association, 2013). Many studies have shown that individuals with ASD have difficulties in processing social information from an early age, such as faces and languages, demonstrating a failure to recognize

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people (Behrmann, Thomas, & Humphreys, 2006) or having receptive and expressive language impairments (Mody & Belliveau, 2013).

Contrary to the explicitly behavioral deficits in ASD, the neurobiological basis of such deficits is poorly understood. It has been argued that ASD is associated with atypical functional hemispheric lateralization (Lindell & Hudry, 2013). Cerebral lateralization has been described as “a hallmark of human development” (Cai, Van der Haegen, & Brysbaert, 2013). The potential advantages of cerebral lateralization are to save on neural circuitry and increase the neural capacity (Vallortigara & Rogers, 2005). In many tasks, the strong lateralization of the tasks in different hemispheres results in better behavioral performance (e.g. Bach et al., 2010; Rogers, Zucca, & Vallortigara, 2004). The atypical cerebral lateralization is considered a risk factor for a number of neurobehavioral disorders including ASD (Moncrieff, 2010). Brain imaging studies have found that, for most people, the dominant hemisphere of language processing locates in the left rather than the right, and is the opposite for face recognition. Reduced or reversed patterns of lateralization were related to language and facial recognition impairments (Behrmann & Plaut, 2014; De Guibert et al., 2011). Given that the major symptoms of ASD were language and face recognition impairments, examination of the hemispheric lateralization pattern can help us understand the potential neural mechanism of ASD.

The abnormal lateralization in ASD typically showed reduced hemisphere dominance or more bilateral recruitment of homologous regions of the cortex in processing faces and language (Jung, Strother, Feil-Seifer, & Hutsler, 2016). For face processing, right-hemisphere dominance was typically found in humans (e.g. Frässle, Paulus, Krach, & Jansen, 2016; Rossion, Joyce, Cottrell, & Tarr, 2003). In contrast, individuals with ASD showed weaker right-hemisphere lateralization or a bilateral effect. These atypical lateralization patterns in ASD have been found consistently by using different neural imaging techniques, including functional magnetic resonance imaging (fMRI) (Critchley, 2000; Scherf, Elbich, Minshew, & Behrmann, 2015; Whyte, Behrmann, Minshew, Garcia, & Scherf, 2016), event-related potentials (ERPs) (Cygan, Tacikowski, Ostaszewski, Chojnicka, & Nowicka, 2014; Webb, Dawson, Bernier, & Panagiotides, 2006), and functional near-infrared spectroscopy (fNIRS) (Jung et al., 2016).

For language processing, most typically developed individuals have presented a left-hemisphere dominance (e.g., Knecht et al., 2000; Rossion et al., 2003). However, for individuals with ASD, diminished left lateralization of brain activation or more engagement of the right hemisphere in performing language-related tasks was often reported, including in the verbal fluency task (Kleinhans, Müller, Cohen, & Courchesne, 2008), the auditory phrase-recognition task (Anderson et al., 2010), the speech processing task (Eyler, Pierce, & Courchesne, 2012; Flagg, Cardy, Roberts, & Roberts, 2005), and the semantic comprehension task (A. T. Wang, 2006). Specifically, in written word processing, Cygan et al. (2014) reported that the N170 amplitudes induced by written names were higher in the left hemisphere than those in the right for typically developed adults (i.e., a left-hemisphere lateralization), whereas ASD showed bilateral lateralization.

In summary, a number of studies in alphabetic languages have found that individuals with ASD exhibited abnormal functional lateralization in face and language processing. Yet, whether Chinese children with ASD show similar atypical lateralization effects in processing face and language-related stimuli is largely unknown. Although a similar right-lateralization pattern to the western population has been found in the Chinese population for face processing, the lateralization pattern for language processing seems quite different between western populations and Chinese populations, especially in written word processing. Different from a left-lateralization for written word processing in alphabetic languages, Chinese character recognition was found to require more engagement in the right hemisphere (Tan et al., 2001, 2000; Tan, Laird, Li, & Fox, 2005) due to its complex visual-spatial structure, which typically resulted in a bilateral activation pattern (Cao et al., 2010; Liu, Dunlap, Fiez, & Perfetti, 2007; Liu & Perfetti, 2003; Tong, Maurer, Chung, & McBride, 2016; Yum, Holcomb, & Grainger, 2011) or a right-lateralization pattern (Śmigasiwicz et al., 2010). Thus, the lateralization deficit in Chinese children with ASD for written word processing might be different compared with those people with ASD from countries that use alphabetical languages.

The aim of this study was two-fold: (1) to investigate whether Chinese children with ASD also show similar lateralization deficits in processing human faces with reduced right lateralization compared with controls; and (2) to examine whether Chinese children with ASD present language-specific lateralization deficits in processing written words compared with people with ASD who use alphabetic languages. We measured the hemispheric lateralization of N170 for word and face recognition in Chinese children with ASD using the tachistoscopic visual half-field paradigm with event-related potentials (ERPs). It is known that the early component N170 at occipital-temporal sites is sensitive to face and visual words compared with other objects (Schweinberger & Burton, 2003). N170 is a relatively stable and large response that can be easily identified despite the poor signal-to-noise ratio of ERPs (Rossion, 2014). A large number of ERP studies have found the right-lateralized N170 for face recognition and the left-lateralized N170 for visual words in alphabetic languages (e.g., Cygan et al., 2014; Maurer, Brandeis, & McCandliss, 2005; Rossion et al., 2003; Rossion, Kung, & Tarr, 2004; Schweinberger & Burton, 2003; Yoncheva, Blau, & Maurer, 2010). Some researchers believed that the N170 abnormalities could be “diagnostic and treatment monitoring biomarkers for social dysfunction”, including ASD (Feuerriegel, Churches, Hofmann, & Keage, 2014). In addition, we were also interested in the relationship between the hemispheric lateralization and reading skills. Studies have found that strong lateralization was associated with better reading performance (Chiarello, Welcome, Halderman, & Leonard, 2009), and the emergence of face lateralization was even correlated with reading competence (Dundas, Plaut, & Behrmann, 2013). Thus, children were asked to complete a behavioral test, the rapid automatic naming (RAN) test. This test was often used to measure reading-related skills (Wei et al., 2014; Wolf et al., 2002), and the task is easy for children with ASD to accomplish. We hypothesized that Chinese children with ASD should also show atypical lateralization compared with typically developing Chinese children for both faces and word recognition; the atypical pattern of ASD in a Chinese cohort might be similar to previous results for faces but different from the results for cohorts that use alphabetical languages.

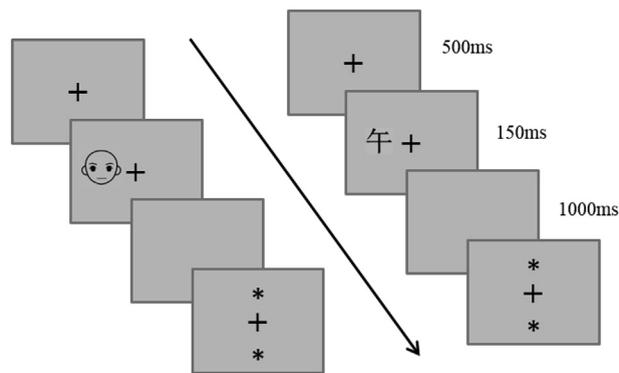


Fig. 1. Experimental procedure for ERP.

2. Methods

2.1. Participants

Eighteen typically developing children [TDC; 14 males; age range: 8-13 y, mean = 9.39, standard deviation (SD) = 1.65; 18 right-handed) and 20 children with ASD (18 males; age range: 6-16 y, mean = 11.05, SD = 3.05; 17 right-handed) took part in the study. Children with ASD were recruited from Peking University Sixth Hospital. They were clinically diagnosed by licensed child and adolescent psychiatrists according to the Diagnostic and Statistical Manual of Mental Disorders-IV (DSM-IV) criteria. No other psychiatric disorders or nervous system diseases were reported. All participants' visual acuity or corrected visual acuity were normal. Written consent was obtained from each participant's parent prior to the experiment. The present study was approved by the ethics committee of the Institute of Psychology at Chinese Academy of Sciences. All the participants were included in following analysis.

2.2. Stimuli and procedure

Twenty Chinese characters and 20 faces were used as stimuli in the experiment. Chinese characters were selected from grade one and grade two primary school textbooks. The stroke numbers of the Chinese characters were between five and eight. The faces were line drawing pictures.

The tachistoscopic visual half-field paradigm was used in the present study, and the procedure was similar to what used in [Cohen et al. \(2000\)](#) and [Cai, Lavidor, Brysbaert, Paulignan, and Nazir \(2008\)](#). In each trial, a central cross was first presented for five hundred milliseconds. Then, a character or face appeared in the left visual field or the right visual field and lasted for 150 ms. Following a 1000 ms blank, participants were asked to judge whether the stimulus was a character or a face by pressing the “M” or “Z” key, respectively. The procedure of a representative trial is shown in [Fig. 1](#). Key responses for faces and characters were counterbalanced across participants. The eccentricity of stimulus was 3.6° , and the size was $2.9^\circ \times 2.9^\circ$. There were three blocks in total, and each block contained 80 trials, in which 40 trials were Chinese characters and 40 trials were faces. In each block, half of the stimuli were presented in the left visual field and half in the right visual field. The presenting order of stimuli was randomized.

2.3. Rapid automatic naming (RAN) tests

The performances of children's RAN of pictures and digits were collected. Five pictures (flower, book, dog, hand, and shoes) and five digits (2, 4, 6, 7, and 9) were used respectively in the two tasks. Pictures/digits were repeatedly presented visually in random order on a 6×5 row-column grid. Participants were asked to name each picture/digit in sequence as quickly as possible. The total naming time was collected. Each task was conducted twice, and the average score was used as the final RAN score.

2.4. Electroencephalogram recordings

We used an elastic cap with 37 Ag-AgCl electrodes according to the 10-20 international system (NeuroScan Inc., EI Paso, TX, USA). The horizontal electrooculogram (EOG) was recorded by two electrodes placed on the right and left external canthus. The vertical EOG was monitored with two electrodes above and below the left eye. The tip of the nose served as a reference, and the electrodes between FPZ and FZ served as the ground electrodes. In order to reduce preparation time for the young participants, we only recorded occipitotemporal electrodes (TP7/TP8, P7/P8), where the N170 for visual stimuli is usually observed ([Mima, Oluwatimilehin, Hiraoka, & Hallett, 2001](#); [Minnebusch, Suchan, Ramon, & Daum, 2007](#)). The electrical signal was recorded by AC sampling with a 500 Hz sampling rate and amplified with a 0.1–100 Hz band-pass filter. The electrode impedance was kept below 5 k Ω .

2.5. Data analysis

For behavioral data, independent t tests on the accuracy of the ERP experiment and the reaction time of picture/digit RAN were conducted between the two groups. For ERP data, off-line analysis of the EEG signal was performed using Neuroscan 4.3 software. Eye blinks were corrected, and then the data was digitally filtered by band-pass (0.5–30 Hz, 24 dB), segmented with epochs of 1000 ms, and regulated by the baseline correction of –100 ms–0 ms. Artifacts were rejected below –100 μV and above 100 μV. In the present study, two pairs of channels (TP7/TP8, P7/P8) on the temporal area were selected to investigate the N170 component. Peak detection was performed for the time-window of 160–240 ms after the stimulus onset. The peak latency was measured in each participant, and average amplitude was measured between 20 ms before and after the latency. The amplitude of the left hemisphere was represented by the mean value of TP7 and P7 channels, and the amplitude of the right hemisphere was represented by the mean value of TP8 and P8 channels. Three-way repeated-measures analysis of variance (ANOVAs) were conducted for N170 amplitudes and latencies, respectively, with a between-subject factor (group: TDC, ASD), and two within-subject factors (stimulus type: Chinese character, face; location: left hemisphere, right hemisphere).

Even though there was a marginally significant difference between the two groups in artifact-free trials [ASD mean (SD) = 170 (57); TDC mean (SD) = 201 (42); $t = 1.94, p = 0.06$], sufficient artifact-free ERP data were obtained from all children with ASD (at least 37 trials per stimulus type).

3. Results

3.1. Behavioral results

Only 29 children's behavioral results in the judgment task of the ERP experiment were recorded successfully due to some technical reasons (16 for TD group and 13 for ASD group). Based on these data, it showed that the accuracy of ASD was significantly lower than that of TDC [ASD mean (SD) = 0.70 (0.21); TDC mean (SD) = 0.91 (0.16); $t = 3.01, p < 0.01$].

All children completed the RAN tasks. The naming time of ASD was longer than that of TDC in both picture RAN [ASD mean (SD) = 26.68 (9.10) s; TDC mean (SD) = 20.94 (3.05) s; $t = -2.66, p < 0.05$] and digit RAN [ASD mean (SD) = 14.32 (6.65) s; TDC mean (SD) = 10.92 (2.14) s; $t = -2.08, p < 0.05$].

3.2. ERP results

The mean and SD of amplitudes and latencies for processing faces and Chinese characters are shown in Table 1 for groups TDC and ASD. The waveforms of the TDC and ASD groups for processing faces and Chinese characters in electrodes of TP7, P7, TP8, and P8 are shown in Fig. 2.

N170 Amplitudes. Results showed a significant main effect of group ($F_{(1,36)} = 5.21, p < 0.05, \eta^2 = 0.13$), with higher N170 amplitudes for the TDC group than the ASD group. The main effect of location was also significant ($F_{(1,36)} = 11.96, p < 0.01, \eta^2 = 0.25$), with higher amplitudes for the right hemisphere than the left hemisphere. The interaction between group and location was significant ($F_{(1,36)} = 4.25, p < 0.05, \eta^2 = 0.11$). For the TDC group, the amplitudes in the right hemisphere were significantly higher than those in the left hemisphere ($F_{(1,36)} = 14.47, p = 0.001, p < 0.05/4 = 0.0125$), whereas there was no significant difference for the ASD group between left and right hemispheres ($F_{(1,36)} = 1.03, p = 0.32$). Another way to show the interaction effect is that in the left hemisphere, there was no significant difference between the two groups ($F_{(1,36)} = 2.56, p = 0.12$); whereas in the right hemisphere, the ASD group exhibited significantly lower amplitudes than the TDC group ($F_{(1,36)} = 6.96, p = 0.012, p < 0.05/4 = 0.0125$). No other effects or interactions were significant.

N170 Latencies. Results showed a significant main effect of type ($F_{(1,36)} = 15.50, p < 0.001, \eta^2 = 0.30$), with shorter latencies of N170 induced by faces than by Chinese characters. There was also a significant main effect of group ($F_{(1,36)} = 4.25, p < 0.05, \eta^2 = 0.11$), with shorter latencies in the ASD group than in the controls. The interaction between group and type was also significant ($F_{(1,36)} = 8.80, p < 0.01, \eta^2 = 0.20$). The ASD group exhibited shorter latencies than the control group only for processing Chinese characters ($F_{(1,36)} = 9.85, p = 0.003, p < 0.05/4 = 0.0125$), whereas there was no significant latency difference between the two groups for processing faces ($F_{(1,36)} = 0.29, p = 0.59$). Another way to show the interaction effect is that for the TDC group, the

Table 1
Mean (SD) of N170 amplitudes (μV) and latencies (ms) for TDC and ASD groups.

	Chinese character		Face	
	Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere
N170 Amplitude				
TDC	-6.94(6.69)	-11.27(7.60)	-6.17(6.41)	-9.95(8.07)
ASD	-2.75(6.52)	-3.91(7.75)	-3.84(6.55)	-4.74(7.79)
N170 Latency				
TDC	221(17)	216(19)	201(19)	200(17)
ASD	200(21)	199(22)	198(20)	196(23)

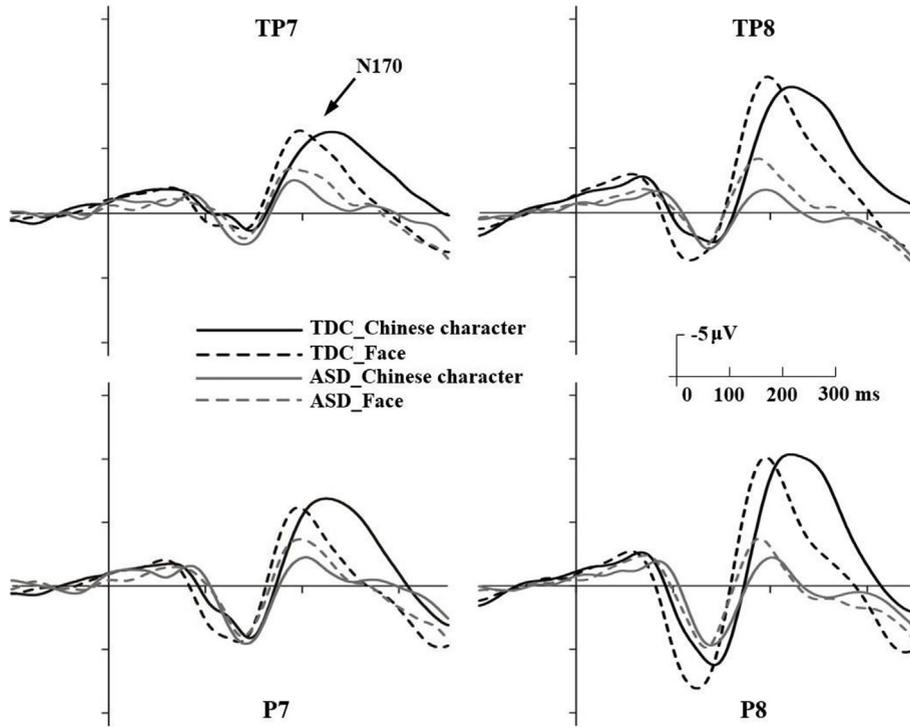


Fig. 2. Waveforms of TDC and ASD groups for conditions of Chinese character and face in both hemispheres.

latencies of N170 induced by faces were significantly shorter than those for Chinese characters ($F_{(1,36)} = 22.63, p < 0.001$), whereas there was no significant difference for the ASD group ($F_{(1,36)} = 0.50, p = 0.49$). No effect of hemisphere or interaction between hemisphere and group was found. No other effects or interactions were significant either.

Since in the present study the control group was not strictly matched with the ASD group in age and other factors, we re-conducted the three-way repeated-measures ANOVAs with age as a covariate to further examine the results. The similar results were found and the new results are listed below.

For N170 amplitudes, the interaction between group and location was marginally significant ($F_{(1,35)} = 3.46, p = 0.071, \eta^2 = 0.09$). Post-doc analysis showed the amplitude in the right hemisphere were higher than that in the left hemisphere ($F_{(1,35)} = 12.92, p < 0.01$) for typically developing children, whereas no significant difference was found for ASD children between left and right hemisphere ($F_{(1,35)} = 1.04, p = 0.31$). Another way to show the interaction effect is that in the left hemisphere there was no significant difference between the two groups ($F_{(1,35)} = 0.95, p = 0.34$), while in the right hemisphere ASD group exhibited marginally lower amplitudes than controls ($F_{(1,35)} = 4.07, p = 0.051$). No main effects or other interactions were significant.

For N170 latency, the interaction between group and type was significant ($F_{(1,35)} = 10.81, p < 0.01, \eta^2 = 0.24$). Post-doc analysis showed ASD children exhibited shorter latencies than controls only for processing Chinese characters ($F_{(1,35)} = 6.09, p < 0.05$), while no significant difference between two groups was found for processing faces ($F_{(1,35)} = 0.29, p = 0.59$). Another way to show the interaction effect is that the latencies of N170 induced by faces were significantly shorter than Chinese characters for typically developing children ($F_{(1,35)} = 25.07, p < 0.001$), while there was no significant difference between the two types of stimuli for the ASD group ($F_{(1,35)} = 0.14, p = 0.71$). No main effects or other interactions were significant.

With a small stimulus set, ERP amplitudes could be reduced over the course of the experiment due to neural adaptation. Previous studies also found different neural adaptation profiles between ASD and TDC (Kleinhans et al., 2009; Schipul & Just, 2016). We attempted to compare the N170 amplitude of the first half trials with that of the second half trials in order to investigate the contribution of neural adaptation to the ERP difference. As shown in Table 2, a three-way repeated-measures ANOVA were conducted, with a between-subject factor (group: TDC, ASD), and two within-subject factors (stimulus type: Chinese character, face;

Table 2
N170 amplitudes of different times.

	Early (first-half trials)		Late (second-half trials)	
	Chinese character	Face	Chinese character	Face
TDC	-11.13 ± 7.65	-11.58 ± 7.78	-9.85 ± 6.43	-10.18 ± 6.94
ASD	-6.04 ± 5.41	-7.74 ± 6.29	-5.51 ± 8.30	-6.92 ± 7.74

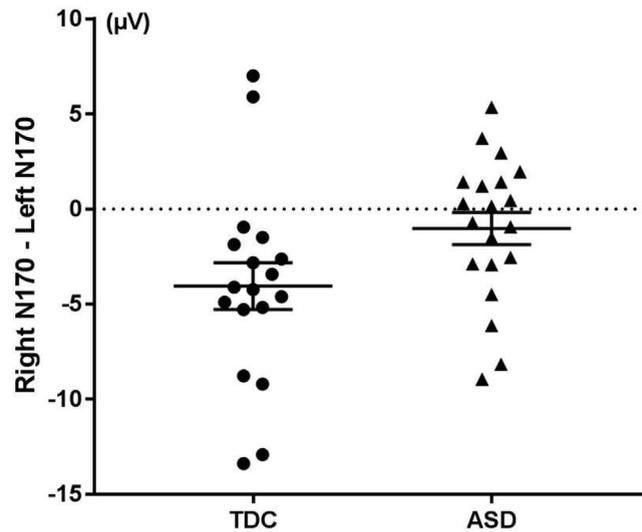


Fig. 3. Scatterplots of the lateralization effects for TDC and ASD groups for conditions of character and face.

time: early, late). Results showed only a marginally significant group main effect ($F_{(1,36)} = 3.90, p = 0.057, \eta^2 = 0.11$), the amplitude of ASD children were lower than that of typically developing children. No other main effects and interactions was significant. It suggested that the N170 difference between two groups may not be related to the neural adaptation.

3.3. Atypical lateralization of N170 and its correlation with RAN in ASD

The significant interaction between group and location of the amplitudes of N170 indicates a deficit of N170 lateralization in ASD. To confirm this, we further conducted independent t tests on the lateralization index (LI = right N170 - left N170) across both conditions (the combination of characters and faces) between the ASD and TDC groups. As N170 is a negative waveform, negative LI indicates right lateralization; positive LI indicates left lateralization; and LI close to zero indicates no lateralization. A significant group difference of LI was found between ASD and TDC [ASD mean (SD) = -1.03 (3.78), TDC mean (SD) = -4.05 (5.23); $t = -2.06, p < 0.05$]. A post hoc t-test comparing LI in each group with zero showed no lateralization of N170 in the ASD group ($t = -1.22, p = 0.24$) and right lateralization of N170 in the TDC group ($t = -3.29, p < 0.01$), as shown in Fig. 3.

Partial Pearson correlations between the lateralization index of N170 and the average reaction time of the two RANs were conducted with age as a covariate for the ASD and TDC groups separately. There was a significant correlation between LI and RAN time for the ASD group ($r = 0.55, p < 0.05$): for ASD, the reduced right lateralization of N170 (more positive LI), the longer the rapid naming time. The correlation in the TDC group was marginally significant ($r = 0.42, p = 0.096$). The scatterplots for the correlations are shown in Fig. 4.

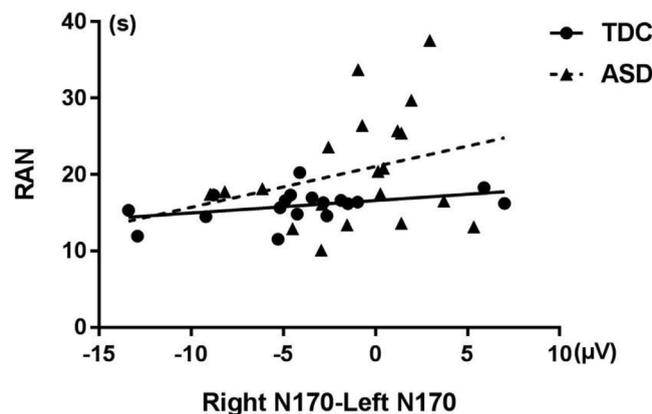


Fig. 4. Correlations between the lateralization of N170 and rapid automatic naming.

4. Discussion

In the present study, we have shown that Chinese children with ASD exhibited atypical lateralization of N170 in processing both faces and Chinese written characters. Chinese children with ASD showed reduced right lateralization in processing faces and written characters compared with controls: typically developing children show right lateralization of N170 in processing both face and written characters, whereas Chinese children with ASD exhibit no lateralization of N170 for both faces and written characters. The diminished right lateralization for processing faces in Chinese children with ASD than for controls was similar to the deficits shown in people with ASD who use alphabetic languages. However, the reduced right lateralization for processing characters in Chinese children with ASD than in controls was different from the pattern found in alphabetic language recognition in those with ASD. This work represents a major advance for the understanding of the brain mechanism of ASD from a Chinese-culture background.

We found that Chinese children with ASD showed diminished right lateralization than the control group, which is consistent with what has been reported by studies from the western culture and alphabetic languages (Critchley, 2000; Cygan et al., 2014; Scherf et al., 2015; Webb et al., 2006). More specifically, our study and previous studies from alphabetic languages both showed that typically developing children showed right-hemispheric advantages in processing faces (e.g., Frässle et al., 2016; Rossion et al., 2003). This may suggest a common nature in processing faces across different languages and cultures. In contrast, Chinese children with ASD showed no lateralization in N170, which also corroborates previous neuroimaging studies from alphabetic languages (Critchley, 2000; Jung et al., 2016; Scherf et al., 2015; Webb et al., 2006; Whyte et al., 2016). This may indicate that the atypical brain lateralization deficit for face processing in ASD from different cultures and language backgrounds is driven by similar underlying mechanisms.

Our results also showed that the atypical lateralization in face recognition for ASD children was mainly driven by reduced N170 amplitudes in the right hemisphere. This decreased activation in the right hemisphere in ASD children might indicate a deficit of ASD in processing configural information during face recognition, because it has been suggested that face processing requires the perception of subtle configural or spatial relations among the facial features (Dundas, Best, Minshew, & Strauss, 2012) and a large number of studies have demonstrated that the left hemisphere specialized in processing local feature information whereas the right hemisphere specialized in processing global configuration information (Atchley & Atchley, 1998; Fiebelkorn, Foxe, McCourt, Dumas, & Molholm, 2013; Volberg, Kliegl, Hanslmayr, & Greenlee, 2009; Weissman & Woldorff, 2005). More broadly, the atypical lateralization of N170 that we found in Chinese children with ASD might support the social motivation hypothesis that has been proposed to explain the atypical neural responses to faces in ASD (Critchley, 2000; Dawson et al., 2002; Dawson, Webb, & McPartland, 2005; Grelotti, Gauthier, & Schultz, 2002). According to the social motivation hypothesis, the brain impairment in children with ASD is due to difficulty in forming representations of the reward value of social stimuli during a critical period of early brain development. Therefore, children with ASD show deficiency in attending stimuli with social information, such as faces, ultimately resulting in the brain abnormalities in face recognition.

With respect to character recognition, Chinese children with ASD showed a specific brain deficit pattern. Typically developing children exhibited right lateralization for N170 with higher N170 amplitude in the right hemisphere than in the left hemisphere, whereas children with ASD showed diminished right lateralization of N170 during Chinese character processing, and this atypical lateralization was derived from the reduced activation in the right hemisphere. These N170 effects found in control children and ASD children are different than what has been reported in alphabetic languages, in which control children show left lateralization of N170 and ASD children show reduced left lateralization (Anderson et al., 2010; Cygan et al., 2014; Eyster et al., 2012; Flagg et al., 2005; Kleinhans et al., 2008). Rather, the N170 effects for Chinese children with ASD and their controls in character recognition were similar to their N170 effects for face recognition. This striking finding for Chinese character recognition might be due to the special characteristics of Chinese characters. First, Chinese characters represent words graphically and rely on visual-spatial decoding (Liu, Tian, Li, Gong, & Lee, 2009). Second, Chinese characters have complex spatial structures and contain configural information (Perfetti, Cao, & Booth, 2013). Third, Chinese characters were found to be able to elicit face-like inversion effects (Wang, Kuo, & Cheng, 2011). Fourth, Chinese characters and faces may share similar neural structures in the ventral occipitotemporal cortex at the stages of visual processing (Liu et al., 2009). Thus, our results might suggest that the atypical lateralization of word and face recognition in Chinese children with ASD may share common underlying underpinnings.

However, it is noteworthy that the atypical lateralization for word and face recognition in ASD children found here is only at group level. At the individual level, 2 out of 18 typically developing children showed left-lateralization rather than right-lateralization and several individuals with ASD also showed right-lateralization (as shown in Fig.3). Such individual differences are also reported in Wilson and Bishop (2018) study. With a large sample of typically developing native English speakers as participants, they found considerable variability in language lateralization using functional transcranial Doppler ultrasound. Among the 156 typically developing children, aged between 6 and 12 years, only around 60% of them showed evidence of language lateralization in the expected direction (left lateralization for English speaking children). In addition, the incidence of right lateralization for language in the typically developing children (19.90%) were higher than in the children with developmental language disorder (9.3%). The results suggest that atypical laterality is not inconsistent with typical language development, and the relationship between laterality and normal brain function need to be further investigated with larger sample size. Likewise, with a small sample of participants and inadequate group matching, the generalization of atypical lateralization for word and face recognition in the children with ASD found in this study should be careful.

Finally, we observed an association between hemispheric lateralization of N170 and rapid naming speed in ASD children: the reduced right lateralization of N170, the slower the speed of rapid naming tasks (the longer rapid naming time) for ASD children. Rapid naming speed has been demonstrated to correlate with reading skills such as word identification (Wei et al., 2014; Wolf et al.,

2002) and text reading (Young & Greig Bowers, 1995). Rapid naming speed has been widely used as an index to differentiate reading ability (Ho, Chan, Lee, Tsang, & Luan, 2004; Ho, Chan, Tsang, & Lee, 2002; Jones, Branigan, Hatzidaki, & Obregón, 2010; Qian & Bi, 2014, 2015; Shu, McBride-Chang, Wu, & Liu, 2006; Yang, Yang, Chen, Zhang, & Bi, 2016; Zhao, Qian, Bi, & Coltheart, 2014; Zhao, Yang, Song, & Bi, 2015). Previous studies have also found that strong lateralization was associated with better reading performance and that poor readers recruited more bilateral hemispheres in word recognition (Chiarello et al., 2009) and the phonological processing task (Bach et al., 2010). Thus, the reduced right lateralization in processing faces and written characters in ASD children indicated an inefficient cognitive functioning, which might be associated with their difficulties of reading-related skills and reading impairments.

It should be noted that we did not observe significant lateralization deficits in ASD for the latency of N170. This may suggest that the lateralization deficit of N170 in ASD might only present in the amplitude but not in the latency. However, in the present study, we found that typically developing children exhibited shorter latencies for faces than for Chinese characters, reflecting a speed advantage for processing faces, whereas children with ASD did not show this advantage. This result might be consistent with previous studies, which found typically developing children showed faster responses to faces than objects, but children with ASD showed no difference in ERP latencies between these two kinds of stimuli or even exhibited slower latencies to faces (Dawson et al., 2005; Webb et al., 2006). This may suggest that ASD is associated with a failure of processing speed advantage for faces.

It should also be noted that we found that the latency of N170 of Chinese ASD children was shorter than that of typical developing children specifically in processing Chinese characters, but not in processing faces. Our finding is inconsistent with studies of previous alphabetic languages, as previous studies have reported that individuals with ASD had longer latencies than controls and this delayed latency was apparent across both faces (McPartland, Dawson, Webb, Panagiotides, & Carver, 2004) and other stimuli such as vehicles (Hileman, Henderson, Mundy, Newell, & Jaime, 2011). The longer latencies found in ASD children in processing faces and other objects suggest a slower general processing speed in ASD (Hileman et al., 2011). However, our Chinese children did not show this general processing speed deficit, as we did not find a significant group difference in N170 latency for face recognition between ASD children and controls. On the contrary, we found a shorter latency of N170 in ASD children in processing Chinese characters, which might reflect the potential advantages of Chinese children with ASD. The strength and enhancement of ASD has previously been observed in many aspects, including the superior perception of local visual features and the enhanced performance of visual search and motion perception (Dakin & Frith, 2005; Foss-Feig, Tadin, Schauder, & Cascio, 2013; Joseph, Keehn, Connolly, Wolfe, & Horowitz, 2009). Some studies also found that the visual motion perception was associated with reading ability and orthographic awareness of the visual word, especially for Chinese children (Meng et al., 2005; Qian & Bi, 2014). The new finding in this study might be specific to Chinese children with ASD, and the related underlying mechanisms for both cases might require further investigations.

4.1. Limitations and future directions

There were several limitations to this study. First, the number of participants in each group was relatively small. Second, the age range of the ASD group was large, and the control group was not strictly matched with the ASD group. Results showed the interaction between group and location became insignificant when considered the age as a covariate, suggesting that age might have contributed to ERP difference. Future studies should use larger sample sizes and a stricter matching of the control group to further examine the atypical pattern of N170 lateralization in Chinese children with ASD. Third, given that the behavioral results of the ERP task were not recorded completely, we could not to conduct the analysis only with the participants whose behavioral scores were above chance level. Besides, the accuracy for some children is poor in the ASD group and this may have contributed to ERP differences. We should exclude the participants scoring below chance and only analyze the trials with correct responses in the future. Fourth, only Chinese children took part in this study. Future studies should compare Chinese children to children who live in a country with an alphabetic language to find the culture-general and culture-specific effects of the pattern of lateralization.

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