

ORIGINAL ARTICLE

Does learning different script systems affect configural visual processing? ERP evidence from early readers of Chinese and German

Xiaoli Ma¹  | Jing Kang² | Xinran Li¹ | Urs Maurer^{3,4} | Xiaohua Cao² | Werner Sommer^{1,2}

¹Institut für Psychologie, Humboldt-Universität zu Berlin, Berlin, Germany

²Department of Psychology, Zhejiang Normal University, Jin Hua, China

³Department of Psychology, The Chinese University of Hong Kong, Hong Kong, China

⁴Brain and Mind Institute, The Chinese University of Hong Kong, Hong Kong, China

Correspondence

Xiaoli Ma and Werner Sommer, Institut für Psychologie, Humboldt-Universität zu Berlin, Rudower Chaussee 18, 12489 Berlin, Germany.

Email: maxiaolq@hu-berlin.de and sommerwe@hu-berlin.de

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Abstract

Reading is a complex cultural skill requiring considerable training, apparently affecting also the processing of non-linguistic visual stimuli. We examined whether the different visual demands involved in reading different script systems—alphabetic German versus logographic Chinese script—would differentially influence configural visual processing. Our main dependent measure was the N170 component of the ERP, which is considered as a signature of configural processing. In the present study, German and Chinese children ($N = 28$ vs. 27) who had received about one year of formal instruction in their native script system, worked on a series of one-back tasks with naturalistic faces, two-tone Mooney faces and doodles, and on an adaptation task with pairs of faces were either identical or differed in their second-order relations. Chinese children showed larger N170 amplitudes than German children for naturalistic and Mooney faces, specifically indicating superior holistic processing in Chinese children. In contrast, there was no superiority in Chinese children on the second-order adaptation effect at the N170, providing no evidence for differences in second-order relations processing of facial configurations between the groups. Given the sensitivity of the visual system to reading acquisition, these findings suggest that these group differences in holistic processing might be due to the extensive training with the highly complex logographic script system learned by Chinese children, imposing high demands on higher-order visual perception.

1 | INTRODUCTION

Evidence that cultural experience can alter visual perception has been available for over 100 years (Rivers, 1905), with recent research focusing on differences between Western and East Asian cultures (e.g., Blais et al., 2008; Estéphan et al., 2018; Kuwabara & Smith, 2016; Nisbett & Miyamoto, 2005). Because populations in East Asian cultures are often required to master a logographic script

system, which is much more complex than alphabetic script systems, the differential experience of reading different script systems might contribute to cross-cultural differences. Reading, a relatively recent culturally transmitted skill, must rely on pre-existing visual and cognitive functions, which may be recycled for solving the specific problems posed by reading (Dehaene & Cohen, 2007). Hence, learning to read requires intense exercise of visual functions, evolved for other purposes. Conversely, reading

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acquisition may induce changes in the processing of non-verbal visual stimuli, especially for faces. However, it is an ongoing debate whether the training of visual skills in reading will involve a positive transfer to other visual domains (faces) or, instead, destructive competition (e.g., Dehaene et al., 2010; Van Paridon et al., 2021). For example, there have been reports about the consequences of reading acquisition on performance in configural face tasks (Cao et al., 2019; Ventura et al., 2013). In the present study we investigated whether acquiring script systems differing in their demands on visual processing will differentially affect configural processing of faces by comparing logographic Chinese and alphabetic German readers.

There are considerable commonalities of written word and face processing. Both kinds of stimuli are members of a large, relatively homogeneous visual object class and require fast and accurate recognition. Skilled readers have gained expertise for word recognition based on massive training, similar to acquiring face expertise (e.g., Maurer et al., 2008; McCandliss et al., 2003; Wong et al., 2012). Both word and face recognition involve configural processing encoding spatial relations between features (e.g., Maurer et al., 2002; Ventura et al., 2019; Wong et al., 2019). Although words and faces seem to compete for representations in the ventral visual cortex (e.g., Cantlon et al., 2011; Centanni et al., 2018; Dehaene et al., 2010), two anatomically neighboring sites in this region, the “visual word form area (VWFA)” and the “fusiform face area (FFA)”, respectively, are held to be selective for these stimuli (e.g., Baker et al., 2007; Golarai et al., 2020; Nestor et al., 2013; Pinel et al., 2015; Tarr & Gauthier, 2000). Both areas have been associated with a pronounced negative-going N170 (N1 in some studies) component in the ERP, elicited by both words and faces (e.g., Brem et al., 2006; Henson et al., 2003; Herrmann et al., 2005) and held to be a neural signature of configural processing (e.g., Eimer et al., 2011; Rossion et al., 2003; Wang et al., 2011).

Logographic Chinese and alphabetic scripts vary greatly in visual complexity as defined by the inventory and complexity of graphemes (Chang et al., 2016). The graphemes correspond to letters and their combinations in alphabetic systems and characters in Chinese script. The set size of the grapheme inventory is much larger for Chinese characters than for alphabetic letters (>3000 characters vs. 30–40 letters counting both upper and lower case). Chinese characters show a fairly uniform square-shaped outline but are internally organized much more complex (e.g., left–right [咪], top–down [吕], or inside–outside [回]) with up to 50 strokes as compared to the linear, left–right spatial configuration of alphabetic letters within a word (Chen & Kao, 2002). In sum, considering the set sizes of graphemic elements and the complexity of spatial configurations, Chinese and alphabetic scripts differ strongly

in their demands on visual processing and memory (e.g., Alvarez & Cavanagh, 2004; Xu & Chun, 2006).

Previous studies indicated a stronger association between pure visual skills and logographic Chinese reading as compared to alphabetic script reading (Ho & Bryant, 1999; Huang & Hanley, 1997; Mann, 1985). There is growing evidence that readers of Chinese show advantages in some aspects of visual processing over alphabetic script readers (e.g., Demetriou et al., 2005; Huang & Hanley, 1995; McBride-Chang et al., 2011; Siok et al., 2009). For example, Demetriou et al. (2005) found that Chinese children consistently outperformed Greek schoolchildren in tests of global visuospatial processing. In addition, Yum and Law (2019) found that readers who learned a visually more complex script (e.g., Chinese/Japanese) in early childhood tend to exhibit greater N170 amplitudes to objects than readers of a visually less complex script (e.g., English). Therefore, it may be plausible that differential training of visual perception and memory required for becoming a skilled Chinese reader as compared to an alphabetic script reader might differentially impact non-verbal visual processing, manifesting also in processing other visual stimuli of sufficient complexity, such as faces.

The resemblance between script and face processing is particularly striking for faces and Chinese characters (Tso et al., 2014; Zhou et al., 2012). Similar to faces, Chinese characters are represented graphically at the individual level (i.e., their identities). Although holistic processing of words has been demonstrated in both alphabetic and Chinese expert readers (Ventura et al., 2019; Wong et al., 2011, 2012), we assume that relative to the acquisition of alphabetic script reading, logographic Chinese reading acquisition should involve a relatively greater demand on holistic visual analysis due to the complex spatial configurations of Chinese characters (e.g., Ben-Yehudah et al., 2019; Cao et al., 2015; Mo et al., 2015). Using the complete composite paradigm for face perception (Gauthier & Bukach, 2007), the holistic processing of Chinese characters defined by the obligatory attention to all parts of characters have been demonstrated to be modulated by writing/drawing abilities (Tso et al., 2014, 2020, 2021) which is analogous to the observed pattern in the development of face recognition (Zhou et al., 2012). In line with these findings, it has been suggested that Chinese character reading relies more on low spatial frequencies as compared to alphabetic word reading (Hsiao & Lam, 2013), and that low spatial frequencies support configural processing of faces by conveying global configurational information (e.g., Goffaux et al., 2005; Sergent, 1982). Compared with robustly left-lateralized activation in the ventral occipito-temporal areas in alphabetic word reading, Chinese character reading showed a

bilateral activation due to involvement of the right hemisphere (e.g., Bolger et al., 2005). More specifically, Chinese character processing, like face processing, recruits neural systems in the fusiform areas of the right hemisphere, which is sensitive to configural information (e.g., Liu et al., 2009). Because of these similarities between Chinese characters and faces, we expected a greater transfer from reading acquisition to face processing in Chinese than alphabetic reading. Specifically, the substantial training with visually complex logographic Chinese characters might tune the visual system toward configural processing and transfer to face processing, which we term as script system hypothesis.

Some incidental but consistent evidence supports the script system hypothesis. Larger N170 amplitudes to faces were observed in East Asians (mainly Chinese and Japanese) as compared to Western participants (e.g., Gajewski et al., 2008; Herzmann et al., 2011; Vizioli et al., 2010; Wiese et al., 2014). These findings may reflect superiority in readers of logographic Chinese/Japanese kanji characters in configural face processing. Configural processing has been suggested to involve three levels or facets (Maurer et al., 2002): first-order relations (i.e., the arrangement of facial features such as two eyes above the nose and the mouth), holistic processing referred to “glueing” together the facial features into a Gestalt or whole, and the second-order relations or relative metric distances between facial features. A behavioral study found that Japanese excelled over American participants in two kinds of configural processing, holistic perception, and sensitivity to second-order relations (Miyamoto et al., 2011). Although suggestive, these

studies are inconclusive concerning the script system hypothesis because the participants tested had also learned additional script systems and the studies had not targeted this question.

To test the script system hypothesis, we compared readers of alphabetic German and logographic Chinese in configural processing and, specifically, in terms of its two aspects, both holistic and second-order relation processing (Maurer et al., 2002). We employed a series of one-back tasks and an adaptation task with ERP measures. The one-back tasks used naturalistic faces, Mooney faces (Mooney, 1957), and doodles (complex but meaningless line drawings, see Figure 1). In the adaptation task pairs of adaptor and test faces were either identical or differed in their second-order relations. The tasks were administered to Chinese and German children who had received about one year of formal reading instructions in their native language and acquired basic reading skills, presumably inducing effects in their visual systems (e.g., Cao et al., 2011; Eberhard-Moscicka et al., 2015; Maurer et al., 2006; van de Walle de Ghelcke et al., 2021). Hence, they had been exposed to different training experiences that might differentially affect configural visual analysis.

Our primary focus was the N170 component in the ERP. According to the script system hypothesis, we expected that Chinese children would show larger N170 responses to naturalistic faces than German children. If the enhanced N170 specifically reflects a superiority in holistic processing, a similar group difference in N170 should be observed for Mooney faces, which have to be processed holistically as there are no separable facial features (Mooney, 1957). Besides, if the sensitivity to second-order

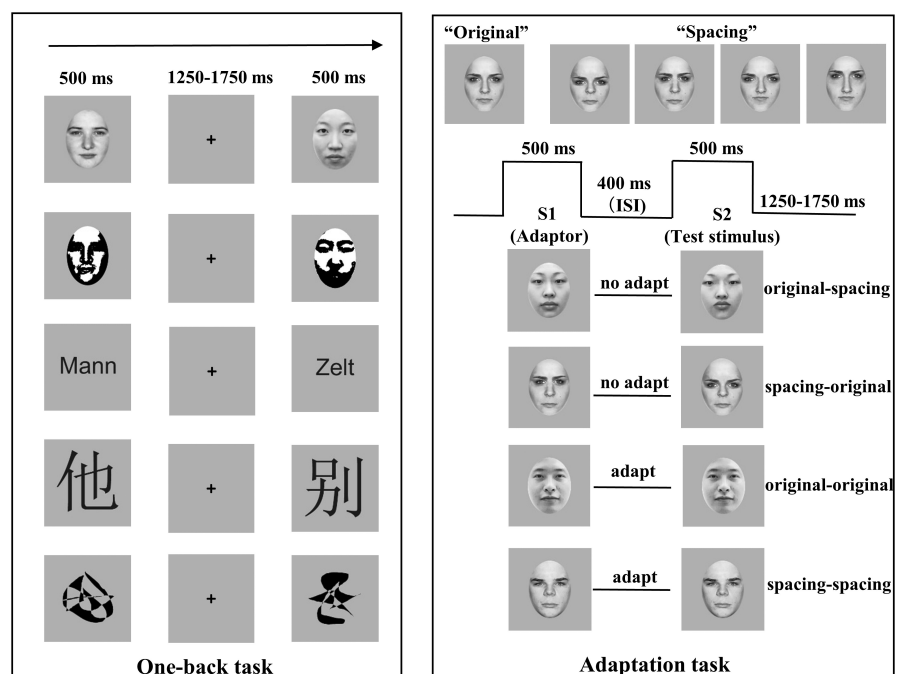


FIGURE 1 Trial structure and examples of the stimuli for one-back task (left panel) and adaptation task (right panel)

relations assessed by adaptation effect, plays a role in the acquired group differences for naturalistic faces, a stronger N170 adaptation effect would be expected in Chinese children. For the control condition with complex abstract patterns without clear relational/configural information, i.e., doodles, we did not expect a group difference.

As a further electrophysiological indicator, we also analyzed the P1 component, the occipital positivity preceding the N170. The P1 is considered to reflect basic and early visual processing, for example, low-level physical stimulus properties, such as size, luminance, and contrast, but also spatial attention (for a review, see Hillyard et al., 1998). This component allowed us to assess contributions of low-level processing and attention to any group differences in the following N170.

2 | METHOD

2.1 | Participants

The initial sample included 45 German and 37 Chinese children, residing in their native countries. After applying strict exclusion and matching criteria as specified below, the final samples consisted of 28 German and 27 Chinese children (Table 1 for details). Formal reading instruction in both Germany and China begins around the age of six. All German children were native German speakers and received alphabetic German script instruction whereas all Chinese children were native Chinese speakers and received logographic Chinese script instruction with additional instruction in an alphabetic script denoting the pronunciations of Chinese characters called pinyin. Participants were tested around the end of the first grade and the beginning of the second grade. All participants had normal or corrected-to-normal vision.

Handedness information was obtained from self-report and/or parent-report using several questions selected from the Edinburgh handedness battery (such as the hand used for writing, drawing, and for using a toothbrush). Prior to the experiment written and verbal informed consent was obtained from the children and their parents. The study was approved by the ethics committee of the departments of Psychology of the Humboldt-University of Berlin and Zhejiang Normal University in accordance with the Declaration of Helsinki.

All participants took tests of fluid intelligence and reading ability. We assessed fluid intelligence with the figural reasoning scale of the Berlin test of fluid and crystallized intelligence for Grades 1–4 (BEFKI-gff; Wilhelm et al., 2014). Each item of the figural reasoning scale consists of a sequence of geometric shapes ordered according to implicit rules. Participants have to infer these rules and choose the next two shapes in the sequence from three alternatives each. Children worked on 11 items of the BEFKI-gff for at most 10 min.

Reading ability in German children was measured with the German 1-min real-word and pseudoword reading fluency test (SLRT-II; Moll & Landerl, 2010). In each test, participants had to read aloud as many words as possible from a list of 156 real-words or pseudowords within one minute. In Chinese children reading skills were assessed with the widely applied Chinese character recognition test and the 1-Min reading fluency test (e.g., Lei et al., 2011; Li et al., 2012; Liao et al., 2015). In the former test, children had to name 150 Chinese characters, ordered in increasing difficulty. The reading fluency test required reading aloud as many two-character Chinese words as possible within one minute from a list of 180. A child was considered as a normal reader if its score in any of these reading tests is not lower than two standard deviations below the mean of the corresponding sample.

	German (<i>N</i> = 28)	Chinese (<i>N</i> = 27)	<i>t</i> -test (<i>df</i> = 53)
Age (years) ^a	7.65 (0.24)	7.76 (0.26)	−1.63
Gender (F/M)	15/13	16/11	/
Handedness (L/R)	4/24	0/27	/
Formal education (months) ^a	13.56 (1.03)	15.00 (0.60)	−6.31**
Fluid intelligence (items) ^a	4.96 (1.93)	5.96 (2.49)	−1.67
1-min reading (German words) ^a	33.86 (20.88)	/	/
1-min reading (pseudo-words) ^a	25.86 (9.31)	/	/
1-min reading (Chinese words) ^a	/	65.04 (19.44)	/
Character recognition (characters) ^a	/	60.93 (30.59)	/

TABLE 1 Descriptive information, reading performance, and test statistics of final samples

^a*M*(*SD*).

***p* < .01.

According to this criterion all of our participants were normal readers (see Table 1). In addition, the reading performance of German children corresponded to the norms (real-word: $M(SD) = 31.67(16.47)$; Pseudoword: $M(SD) = 25.24(9.96)$) while the Chinese children's reading performance was comparable to participants in the study by Zhao et al. (2019) where Chinese character recognition in 127 Chinese children in the first half of second-grade was: $M(SD) = 59.65(23.50)$. Hence, the literacy skills for both Chinese and German corresponded well with their education level.

Several children were excluded from analysis; the reasons were prematurely terminating the EEG part ($N = 2$), technical problems with EEG data ($N = 1$), excessive movements or problems to pay attention in several experimental blocks ($N = 2$), and performance sensitivity >2 SDs below the sample mean ($N = 4$). Also, to match the groups for age, 11 German children <7.3 years, 1 German child and 6 Chinese children >8.1 years were excluded.

2.2 | Stimuli

We administered five one-back tasks with different stimulus materials and an adaptation task with faces. Stimuli for the one-back task were five sets of 16 grey-scale images, showing standardized naturalistic adult faces, Mooney faces (Mooney, 1957), German words, Chinese characters and doodles (see Figure 1 left panel). Eight naturalistic faces each were of Chinese, and Caucasian adults, in equal numbers female and male with neutral facial expression. The same organization pertained to Mooney faces, generated by increasing the contrast in a separate set of 16 faces until each image was two-tone black and white. The visual angle of naturalistic and Mooney faces was approximately $4.7^\circ \times 6.3^\circ$ from a distance of 70 cm. Doodles were black and white line drawings of irregular shapes with visual angle of $5.4^\circ \times 5.6^\circ$ on average. Since the word conditions did not directly address the current goals, we did not detail them here.

For the adaptation task, 16 grey-scale naturalistic face images of different individuals but standardized in the same way as those for the one-back tasks and also balanced for ethnicity and sex, served as original faces (see Figure 1 right panel). Each original face was manipulated in its second-order relations with Adobe CSC 7 software in four ways: (1) Moving down the eyes by 4 mm (0.5° for the viewing distance of 70 cm) and the mouth by 2 mm (0.2° for the viewing distance of 70 cm), (2) moving the eyes together by 4 mm and moving down the mouth by 2 mm, (3) moving the eyes apart by 4 mm and moving the mouth upward by 2 mm, or (4) moving up the eyes by 4 mm and

the mouth by 2 mm. All faces subtended visual angles of $4.7^\circ \times 6.3^\circ$.

2.3 | Procedure

German and Chinese participants were individually tested by a female experimenter in an EEG laboratory and a separated testing area adjacent to a primary school, respectively. Participants were seated on a comfortable chair 70 cm away from a computer monitor. Presentation 1.0 and E-prime 3.0 software (Psychology Software Tools, Pittsburgh, PA) controlled the experiments in Germany and China, respectively. In all tasks, stimuli were shown in the center of the screen on a light grey background. The order of the adaptation task and the set of one-back tasks was balanced across participants. The five different one-back tasks were presented about equally often at each possible position.

The series of five one-back tasks were preceded by a practice task with 20 pictures of houses. Each one-back task consisted of 78 trials of a given stimulus category. The first six trials in each task were training items with one immediate repetition, excluded from the final analysis. The 16 stimuli of each category were presented in pseudo-randomized order with the constraint of 8 (11%) immediate repetitions, serving as target trials. Participants were required to press the space button when they saw a repetition immediately. Stimulus duration was 500 ms followed by an interstimulus interval (ISI) that varied randomly from 1250 to 1750 ms (see Figure 1 left panel). In each task a short break was provided after every 26 trials and a longer pause was given at the end.

The adaptation task included 144 trials divided equally into two blocks. On each trial, two images (S1: adaptor face; S2: test face) were presented successively for 500 ms each, separated by a 400-ms interstimulus interval (see Figure 1 right panel). Original and spacing-modified faces were presented equiprobably as S1 or S2. The intertrial interval varied between 1250 and 1750 ms. All combinations of S1 and S2 on the same trials were images of the same individual, with half of the combinations being identical images (adapt condition) and the other half of trials comprising pairs of S1 and S2 stimuli differing in second-order relations (no adapt condition). Participants were instructed to press the space button when the ethnicities of the current face pair and the immediately preceding face pair differed. There were 10% of ethnicity changes in each block. Participants were given practice trials before the adaptation task, and the experimenter made sure that children had understood the task before working at the test trials. A short break was provided after every 18 trials and a longer pause was made between blocks.

2.4 | EEG recording and preprocessing

EEG was recorded with 39 Ag/AgCl electrodes placed within an elastic cap (Easycap GmbH, Herrsching, Germany) according to the extended International 10–20 System in Germany and China. Two additional electrodes below each eye measured vertical electroocular (EOG) activity. During recordings all channels were referenced to the Cz electrode; AFz served as the ground electrode. Impedances were kept <20 k Ω at a uniform level (Ferree et al., 2001). Signals were amplified using Brain Amps (Brain Products) and sampled at 1000 Hz.

Offline, EEG data were re-calculated to common average reference, digitally high-pass filtered at 0.1 Hz (12 dB/Octave, zerophase-type filter) and low-pass filtered at 30 Hz (24 dB/Octave, zerophase-type filter), using Brain Vision Analyzer 2.0 software. We analyzed ERPs in all non-target trials, epoched at -100 to 500 ms relative to stimulus onset and baseline-corrected to the average amplitude during the 100-ms pre-stimulus interval. Trials were rejected if (1) voltages exceeded ± 100 μ V at any electrode, if (2) the absolute difference between two adjacent sample points exceeded 75 μ V, or (3) if the voltage range of a given channel within an epoch exceeded 150 μ V. After artifact rejection, the average of all stimulus conditions in each task for each child included at least 15 epochs. A mixed ANOVA with a between-subject factor children group and a within-subject factor stimulus condition revealed that Chinese children ($M = 50.57$, $SD = 8.43$) had higher average number of accepted trials across stimulus conditions than German children ($M = 44.42$, $SD = 7.98$), $F(1,53) = 7.72$, $p < .01$, $\eta_p^2 = 0.13$.

Previous studies reported slow-wave activities, especially pronounced in children, overlapping with early ERP components (N1, P2, N2) and affecting their amplitudes and topographies (Dimoska et al., 2007; Johnstone et al., 2003; Johnstone & Barry, 1999). Because our main component of interest, the N170, might be distorted by such slow-wave activity we applied an additional 2 Hz high-pass filter (12 dB/Octave, zerophase-type filter) to remove the slow-wave. These “high-pass filtered” ERPs (bandpass 2–30 Hz) were distinguished from the “broad-band” ERPs before high-pass filtering (bandpass 0.1–30 Hz).

2.5 | Data analyses

2.5.1 | Behavioral analyses

Behavioral performance was assessed as hit rate, false alarm rate, sensitivity, and reaction time (RT). Hit rate was calculated by using the number of target trials, which

were correctly judged as targets divided by the total number of target trials. False alarm rate was calculated as the number of non-target trials judged as targets divided by the total number of non-targets. Sensitivity was calculated as hit rate minus false alarm rate. RT was measured for the correctly judged target trials. However, there were five children (one German, four Chinese) who missed all targets in one or two tasks, resulting in missing RT data. Because these children had always looked at the stimuli during EEG recording as noted by the experimenter, they were still included in the final analyses. The missing RT data in these children were imputed by an R-package titled Multivariate Imputation by Chained Equations (MICE). The MICE algorithm used RT data from other tasks and other children to predict and impute missing RT data.

We performed separate unpaired t tests with IBM SPSS Statistics 24 to examine differences between German and Chinese children on hit rates, false alarm rates, sensitivity, and reaction times.

2.5.2 | EEG analyses

Topographic pattern analysis

Our study aimed to compare amplitude differences of ERP components between German and Chinese children. However, when examining component amplitudes at a few predefined electrodes, possible differences in electrical field topography must be taken into consideration (Lehmann & Skrandies, 1980; Michel et al., 1999, 2001). Topographic differences provide important additional information about the spatiotemporal dynamics of visual processing, as they may reflect differences in ERP component generator configurations. To address this question, we applied topographic pattern analysis (spatiotemporal segmentation, Brunet et al., 2011) to separate the ERP data into a limited number of topographical map configurations. A map configuration is a period during which the topography of the electrophysiological activity on the scalp remains stable. Any change of the spatial configuration of the electric field on the scalp reveals a difference between configurations of the underlying intracranial sources. Topographic pattern analysis is insensitive to pure amplitude modulations across conditions (i.e., topographies of normalized maps are compared) and independent of the reference electrode (Brunet et al., 2011). In addition, the influence of slow-wave activity was assessed by comparing topographic pattern analyses for broad-band and high-pass filtered ERPs.

Topographic pattern analysis was conducted in the grand mean ERP data (i.e., from 0 to 400 ms post-stimulus onset) for each stimulus condition and group with topographic atomize and agglomerate hierarchical clustering

(T-AAHC) implemented in Cartool software (Brunet et al., 2011). A given topography had to be present for at least 30 ms and the maximum correlation between different topographies should not exceed 95% (temporal smoothing, see Brunet et al., 2011). Modified cross-validation (CV) and Krzanowski-Lai (KL) criteria were used to determine the optimal number of maps best explaining the group-averaged data sets across stimulus conditions and groups (Brunet et al., 2011; Murray et al., 2008). In the next step, the dominant maps identified in the group-averaged data were then fitted to the ERPs of each participant using spatial fitting procedures, to quantify their representation across subjects and conditions (Brunet et al., 2011). This procedure allowed us to establish how much of the global variance (GEV) of one condition/group was explained by a given segmentation map.

Component analyses

We parameterized the ERP components according to the topographic pattern analysis. Using IBM SPSS Statistics 24, we conducted mixed-design analyses of variance (ANOVA) on ERP component amplitudes and latencies. There were four sets of analyses investigating different questions. Firstly, to investigate the group differences on global configural processing between logographic Chinese and alphabetic German script readers, we performed ANOVAs with a between-subject factor children group (German, Chinese), and within-subject factors hemisphere (left, right) and task (one-back, adaptation) on ERPs to naturalistic faces including faces in the one-back task and adaptors in the adaptation task. Secondly, we performed ANOVAs with a between-subject factor children group (German, Chinese) and a within-subject factor hemisphere (left, right) on ERPs to Mooney faces in one-back task to examine the group differences between two script readers on holistic processing. Thirdly, to examine the group differences between two script readers on the sensitivity to second-order relations during face processing, we conducted ANOVAs with a between-subject factor children group (German, Chinese), and within-subject factor hemisphere (left, right) and adaptation condition (adapt, no adapt) on ERPs to the test faces (S2) in the adaptation task. The sensitivity to second-order relations was measured by the adaptation effect referring to reduced responses for S2 when it is preceded by an identical face with the same second-order relations (adapt condition) relative to when preceded by an identical face but with different second-order relations (no adapt condition). Lastly, we conducted ANOVAs with a between-subject factor children group (German, Chinese) and a within-subject factor hemisphere (left, right) on ERPs to doodles to examine whether any effects observed in the face conditions would also extend to unfamiliar complex visual stimuli that are hard to process configurationally.

3 | RESULTS

3.1 | Behavioral results

Figure 2 showed the behavioral results for the one-back tasks and adaptation task. *T*-tests revealed that Chinese children ($M = 899.04$ ms, $SD = 220.70$) showed significantly shorter reaction time in naturalistic face one-back task than German children ($M = 1012.46$ ms, $SD = 195.30$), $t(53) = 2.02$, $p < .05$, Cohen's $d = 0.53$. In the adaptation task German children ($M = 0.71$, $SD = 0.28$) showed significantly higher sensitivity than Chinese children ($M = 0.41$, $SD = 0.40$), $t(53) = 2.55$, $p < .05$, Cohen's $d = 0.67$. In contrast, German children ($M = 0.07$, $SD = 0.09$) showed lower false alarm rate in adaptation task than Chinese children ($M = 0.17$, $SD = 0.20$), $t(53) = -2.48$, $p < .05$, Cohen's $d = 0.63$. No other group comparisons reached significance (all $ps > .05$).

3.2 | Topographic pattern analyses

Figure 3a,b illustrated the results of topographic pattern analyses on the broad-band ERPs for German and Chinese children in different stimulus conditions. The results revealed that German and Chinese children showed different topographies corresponding to the P1 component in the time window between 70 and 160 ms (Map 6 vs. Map 5), although maps were consistent across all conditions within each group. By contrast, the topographies corresponding to the N170 time range were heterogeneous. Map 3 in the time interval from 160–230 ms, corresponding to N170 was identified in ERPs to naturalistic faces in both tasks and both groups. However, its scalp distribution with positivity in the posterior region was untypical for the N170, and its map strength was quite small. Furthermore, the topographies of Mooney face in the N170 range in German and Chinese were different (Map 4 vs. Map 7). In the doodle condition both German and Chinese children showed only one unitary but group-specific topography during the whole epoch (Map 6 vs. Map 5). Because of these peculiarities, we eliminated the slow activity overlapping the P1 and N170 by high-pass filtering and reapplied topographic pattern analysis.

As in broad-band ERPs, the results of high-pass filtered ERPs (see Figure 3c,d) showed different but within-group consistent scalp topographies of P1 for German and Chinese children (Map 6 vs. Map 7) between about 70 and 160 ms. However, topographies in the N170 range were now much more consistent than in broad-band ERPs. Both groups showed the same map (Map 4) between about 160 and 260 ms, corresponding to the N170 for naturalistic faces, Mooney faces and S2-faces in the adaptation task.

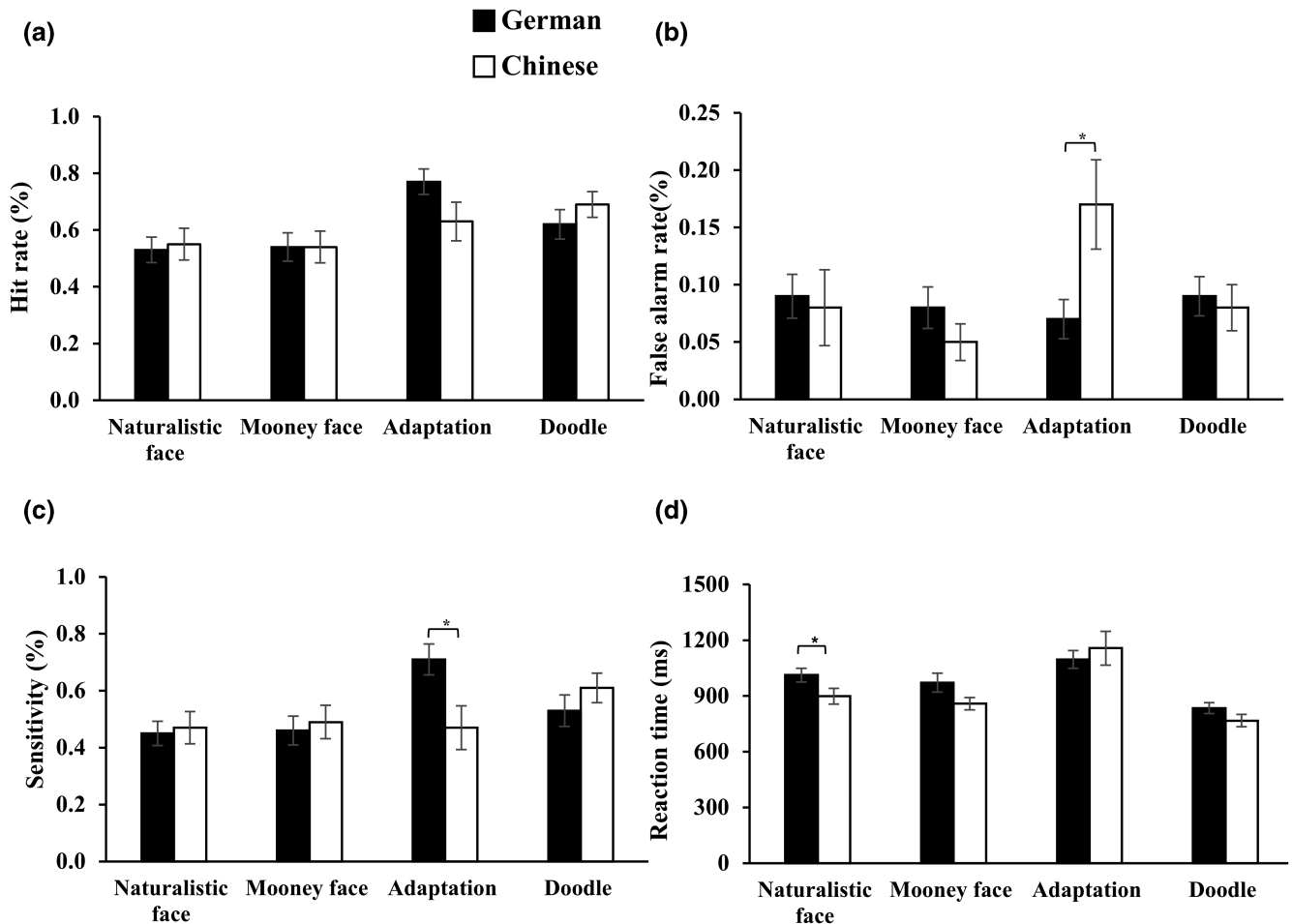


FIGURE 2 Behavioral results on (a) hit rates, (b) false alarm rates, (c) sensitivity, and (d) reaction times in one-back tasks (naturalistic face, Mooney face, and doodle) and adaptation task. Error bars indicate the standard error of the means. $*p < .05$

Besides, this highly consistent map in the N170 range was in line with typical N170 topographies and showed more pronounced strength than that in the broad-band ERPs. In addition, different scalp distributions appeared for the doodle condition between German and Chinese children (Map 3 and 5 vs. Map 4 and 8) between 160 and 260 ms.

The above observations strongly suggested that the slow-wave shift in the broad-band ERP data was responsible for the heterogeneous N170 topographies and their small strengths. Figure S1 in the Supporting Information showed the grand average waveforms of broad-band ERPs and high-pass filtered ERPs to illustrate the effects of slow-wave activity on the N170 component. As a consequence, the fitting procedure and statistical analyses were conducted only on high-pass filtered ERPs.

Statistical analysis was performed using ANOVAs of GEV in two time periods. For the first period (70–160 ms), corresponding to the P1 component, we performed ANOVA on GEV with a between-subject factor children group (German, Chinese) and within-subject factors stimulus condition (naturalistic face_one-back, naturalistic face_adaptor, Mooney face, S2_adapt, S2_no adapt, doodle) and map (map 3, map 4, map 5, map 8) on GVE was conducted. No significant effect involving the factor group was observed (all $ps > .05$). The interaction between stimulus condition and map was significant ($F(1,53) = 24.31$, $p < .001$, $\eta_p^2 = 0.31$). Post-hoc analysis indicated that

S2_no adapt, doodle) and map (map 6, map 7). Results showed that the interaction of children group and map was highly significant ($F(1,53) = 51.86$, $p < .001$, $\eta_p^2 = 0.50$). Post-hoc analysis revealed that German children showed larger GEV for map 6 and smaller GEV for map 7 than Chinese children (all $ps < .001$). Also, post-hoc analysis indicated that the GEV for map 6 was larger than for map 7 in German children whereas the GEV for map 7 was larger than for map 6 in Chinese children (all $ps < .05$). Thus, the representative map for P1 for German and Chinese children was Map 6 and Map 7, respectively. For the second period (161–260 ms), corresponding to the N170 component, a mixed ANOVA with a between-subject factor children group (German, Chinese) and within-subject factors stimulus condition (naturalistic face_one-back, naturalistic face_adaptor, Mooney face, S2_adapt, S2_no adapt, doodle) and map (map 3, map 4, map 5, map 8) on GVE was conducted. No significant effect involving the factor group was observed (all $ps > .05$). The interaction between stimulus condition and map was significant ($F(1,53) = 24.31$, $p < .001$, $\eta_p^2 = 0.31$). Post-hoc analysis indicated that

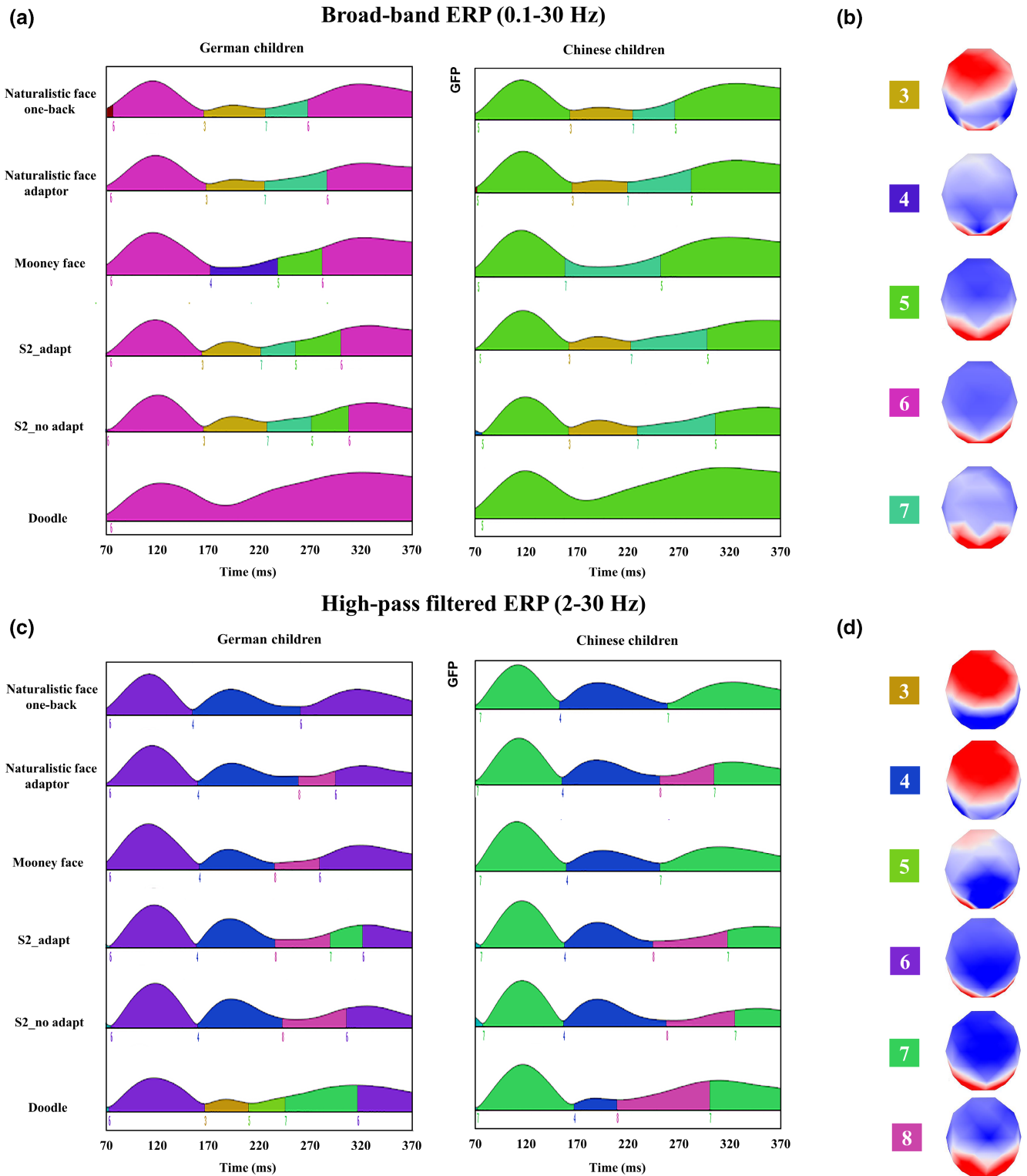


FIGURE 3 Global field power (GFP) and results of the topographic pattern analysis performed on grand average broad-band ERPs (0.1–30 Hz, a and b) and high-pass filtered ERP (2–30 Hz, c and d). (a, c) The temporal distribution of the template map is displayed with different colors for German and Chinese children (left and right sides in panels a and c) between 70 and 370 ms. (b, d) The corresponding template maps are displayed with positive voltages in red and negative voltages in blue. The template map numbers (and their background colors at the left) correspond to the temporal distribution

the GEV for map 4 (i.e., typical N170 topography) was larger than any other maps across stimulus conditions (all $ps < .001$) except the doodle condition (all $ps > .05$).

Therefore, the dominant map for N170, that is map 4, was indistinguishable for German and Chinese children across stimulus conditions, except for doodles.

3.3 | Component analyses

The topographic pattern analysis revealed different topographies of the P1 component in German and Chinese children (see Figure 3c,d) across all stimulus conditions, suggesting different neural generator configurations between groups. A likely source for the difference in ERP topography stems from the differences in head shapes/brain anatomies in Chinese and German children (Ball et al., 2010; Cuffin, 1990; Tang et al., 2018). Because N170 topographies did not differ between groups we can rule out systematic differences in electrode placement between the groups/labs. When surface activities in a certain time interval are distributed differently, as was the case for the P1 time range, amplitude comparisons are close to meaningless. Amplitude differences at a given electrode site might reflect the difference in component strength or topography. In addition, using the maximum across the scalp or global field power is compromised by the unavoidable incomplete coverage of the head surface, again confounding strength and topography. As a consequence of this dilemma, we refrained from further analyzing the P1 components.

As the German and Chinese children showed indistinguishable topographies in the time period corresponding to the N170 component (see Figure 3c,d), we felt justified to compare N170 amplitudes between German and Chinese children at specific electrode sites. However, the N170 was very small for the doodle condition, and peak measures were not reliable in individual participants. Therefore, we parameterized the N170 only for the face conditions. It was measured at the occipitotemporal electrode sites P7 (left hemisphere) and P8 (right hemisphere) frequently used in other studies (e.g., Dundas et al., 2014; Eimer et al., 2010, 2011; Latinus & Taylor, 2006; Rossion & Jacques, 2008) and where N170 amplitudes were most prominent in the present data. The N170 amplitude at P7 and P8 was averaged within a ± 30 ms window centered on the most negative peak voltage detected automatically between 140 and 300 ms after stimulus onset in each hemisphere. The N170 latency was quantified at the latency of the most negative peak voltage at each hemisphere.

3.3.1 | Naturalistic faces

To examine the group differences on global configural processing, we performed the ANOVAs with a between-subject factor group (German, Chinese), and within-subject factors hemisphere (left, right) and task (one-back, adaptation) on N170 amplitudes and latencies to naturalistic faces, including faces of the one-back task and adaptor faces in the adaptation task.

For N170 amplitude (see Figure 4A), the ANOVA revealed a significant main effect of group ($F(1,53) = 5.39$, $p < .05$, $\eta_p^2 = 0.09$). Chinese children ($M = -6.84 \mu\text{V}$, $SD = 3.29$) showed larger N170 amplitudes to naturalistic faces, regardless of task, than German children ($M = -5.03 \mu\text{V}$, $SD = 2.43$). The main effect of hemisphere was also significant ($F(1,53) = 7.62$, $p < 0.01$, $\eta_p^2 = 0.13$). The N170 amplitude was larger in the right ($M = -6.52 \mu\text{V}$, $SD = 3.88$) than in the left hemisphere ($M = -5.33 \mu\text{V}$, $SD = 2.86$), independent of group. To make sure that any observed group differences were not stimulus face race-specific or had to be attributed to visual differences between own- and other-race faces, we conducted a further ANOVA with factors group hemisphere, task and race of faces on N170 amplitudes. The results again yielded the main effect of group ($F(1,53) = 5.64$, $p < .05$, $\eta_p^2 = 0.10$), which was not modulated by race of faces (all $ps > .05$), indicating that the group differences for the face N170 were independent of any stimulus ethnicity effects.

N170 latency yielded a significant interaction between task and group ($F(1,53) = 6.30$, $p < .05$, $\eta_p^2 = 0.11$). The post-hoc tests indicated that German children showed significantly longer N170 latency to adaptor faces in the adaptation task ($M = 206.91$ ms, $SD = 22.72$) than Chinese children ($M = 192.64$ ms, $SD = 19.77$, $p < .05$). Besides, for German children the N170 latency to adaptor faces in the adaptation task ($M = 206.91$ ms, $SD = 22.72$) was significantly longer than to naturalistic faces in the one-back task ($M = 194.69$ ms, $SD = 19.77$, $p < .05$).

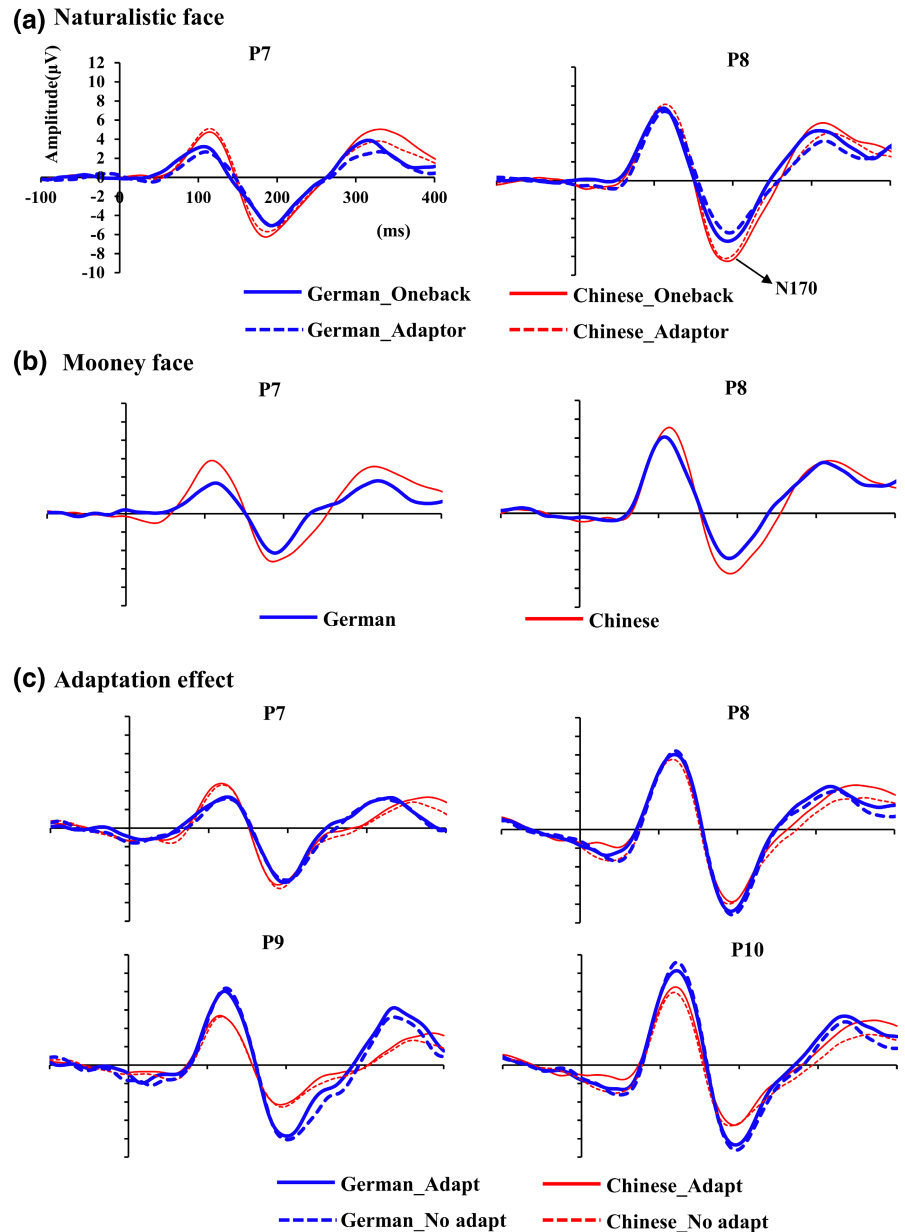
3.3.2 | Mooney faces

To examine the group differences on holistic processing, we performed ANOVAs with a between-subject factor group (German, Chinese) and a within-subject factor hemisphere (left, right) on N170 amplitudes and latencies to Mooney faces in one-back task. For the N170 amplitude (see Figure 4b), there was a significant main effect of group ($F(1,53) = 4.35$, $p < .05$, $\eta_p^2 = 0.08$). Chinese children ($M = -5.94 \mu\text{V}$, $SD = 3.87$) showed significantly larger N170 amplitudes to Mooney faces than German children ($M = -4.12 \mu\text{V}$, $SD = 2.47$). There was no significant effect in N170 latency to Mooney faces (all $ps > .05$).

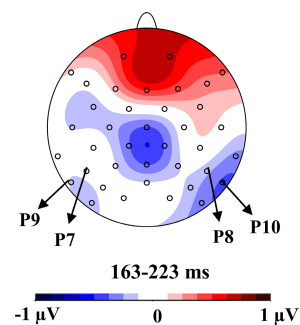
3.3.3 | Adaptation effect

The adaptation effect refers to reduced responses to test faces (S2) when preceded by an identical face (adapt condition) relative to the same face but with altered second-order relations (no adapt condition). The adaptation effect

FIGURE 4 (a, b) The grand average high-pass filtered ERP waveforms for German and Chinese children of Naturalistic faces (a), Mooney faces (b) measured at P7/P8 electrodes. (c) The grand average high-pass filtered ERP waveforms for German and Chinese children of S2 faces recorded at P7/P8 (top panel) and P9/P10 (middle panel) respectively; bottom panel: N170 topographies of adaptation effect (no adapt minus adapt) from 163 to 223 ms for the average ERPs of German and Chinese group



N170 topography for adaptation effect (No adapt condition minus adapt condition)



was used to assess the sensitivity to second-order relations. Thus, to examine the group differences on the sensitivity to second-order relations during face processing, we

conducted ANOVAs with a between-subject factor children group (German, Chinese), and within-subject factors hemisphere (left, right) and adaptation condition (adapt,

no adapt) on N170 amplitudes and latencies to test faces in the adaptation task.

We also observed a significant main effect of hemisphere ($F(1,53) = 10.34$, $p < .01$, $\eta_p^2 = 0.16$), indicating that the N170 amplitude was more negative in the right ($M = -7.23 \mu\text{V}$, $SD = 5.31$) than in the left ($M = -5.54 \mu\text{V}$, $SD = 3.00$), independent of group. Importantly, no significant effects involving the adaption condition for N170 amplitudes and latencies reached significance (all $ps > .05$) although N170 amplitudes to test faces in the adapt condition ($M = -6.24 \mu\text{V}$, $SD = 3.30$) was numerically smaller than in the no adapt condition ($M = -6.53 \mu\text{V}$, $SD = 3.18$).

However, the absence of adaptation effect might be due to the selection of electrodes. According to the N170 topography for adaptation effect (no adapt minus adapt) in the average ERPs of two groups (see [Figure 4c](#) bottom), P9 (left hemisphere) and P10 (right hemisphere) showed the most pronounced adaptation effect. Thus, additional ANOVAs with a between-subject factor group (German, Chinese), and within-subject factors hemisphere (left, right) and adaptation condition (adapt, no adapt) on N170 amplitudes and latencies measured at P9/P10 electrodes were performed.

The results at P9/P10 (see [Figure 4c](#) middle panel) showed a significant main effect of adaptation condition on N170 amplitude ($F(1,53) = 5.52$, $p < .05$, $\eta_p^2 = 0.09$). The N170 amplitude to test faces in the adapt condition ($M = -6.16 \mu\text{V}$, $SD = 3.26$) was reduced relative to the no-adapt condition ($M = -6.72 \mu\text{V}$, $SD = 3.60$). The main effect of group was significant ($F(1,53) = 7.25$, $p < .01$, $\eta_p^2 = 0.12$). German children ($M = -7.56 \mu\text{V}$, $SD = 3.38$) showed larger N170 amplitude to test faces than Chinese children ($M = -5.28 \mu\text{V}$, $SD = 2.86$). A significant main effect of hemisphere was also observed ($F(1,53) = 4.82$, $p < .05$, $\eta_p^2 = 0.08$). The N170 amplitude to test faces was larger in right hemisphere ($M = -6.70 \mu\text{V}$, $SD = 4.30$) than left hemisphere ($M = -5.88 \mu\text{V}$, $SD = 3.30$), independent of group. There were no significant effects on N170 latency (all $ps > .05$).

Additional planned ANOVAs with within-subject factors hemisphere (left, right) and adaptation condition (adapt, no adapt) on the N170 amplitudes and latencies were conducted for each group. In German children there was a significant main effect of adaptation condition ($F(1,53) = 4.40$, $p < .05$, $\eta_p^2 = 0.14$). German children showed reduced N170 amplitudes to test faces in the adapt condition ($M = -7.11 \mu\text{V}$, $SD = 3.48$) as compared to that in the no adapt condition ($M = -8.00 \mu\text{V}$, $SD = 3.66$). In contrast, no significant main effect was observed in Chinese children ($F(1,53) = 1.26$, $p > .05$, $\eta_p^2 = 0.05$) although N170 amplitudes to test faces in the adapt condition ($M = -5.17 \mu\text{V}$, $SD = 2.73$) was numerically smaller than that in the no adapt condition ($M = -5.39 \mu\text{V}$,

$SD = 3.08$). For N170 latency, no significant effect was observed (all $ps > .05$).

4 | DISCUSSION

Reading acquisition is known to affect the visual processing of non-linguistic visual stimuli. Here we investigated whether these effects would be different after learning script systems with different demands on visual and mnemonic processes, such as logographic Chinese versus alphabetic German. We tested German and Chinese children, who had received about one-year of formal reading education, on different aspects of configural processing of face stimuli, using the N170 component of the ERP as the dependent measure. As compared to German children, Chinese children showed larger N170 amplitudes to naturalistic faces and Mooney faces. In contrast, the adaptation effect to second-order relations at N170 did not differ between the groups. Together, these findings argue for a differential effect of script systems on the holistic processing of non-linguistic visual stimuli, as discussed below.

4.1 | A holistic processing advantage in Chinese children

The present study showed that the N170 amplitude to both naturalistic faces of the one-back task and the adaptor faces of the adaptation task was larger in Chinese than in German children, indicating that Chinese children show superior configural face processing over German children. Because the findings with naturalistic faces cannot clarify which specific aspect of configural face processing (Maurer et al., 2002) contributes to the observed group difference on N170, the results from the other face tasks have to be considered. For Mooney faces a similar group difference in N170 amplitude was observed as for naturalistic faces, with larger amplitudes in Chinese than in German children. This finding suggests that the group difference in configural processing can be specified to the level of holistic processing. In contrast, in the adaptation task, the N170 adaptation effect to second-order relations was significant in German but not in Chinese children, indicating no superiority of Chinese children in second-order relations processing in faces. We may therefore conclude that the Chinese children's superiority in configural processing as revealed by the N170 to naturalistic faces can be more specifically attributed to the processing holistic aspects rather than second-order relations.

In addition, although previous studies suggested that the facial physiognomic information contributes to the strategies of face processing (e.g., Wang et al., 2015), the

present differences between Chinese and German participants cannot be explained by differences of facial physiognomic information between Chinese and Caucasian faces. We used the same stimuli in both experiments, consisting in equal parts of same-and other-race faces. Moreover, the results of the analysis provide direct evidence that the observed group differences were not modulated by face ethnicity.

In general, the observed effects on the N170 component to faces are consistent with previous evidence that the N170 is sensitive to configural processing, including the level of holistic and second-order relations processing (e.g., Eimer et al., 2011; Vakli et al., 2014). One should mention that Chen et al. (2013) found an earlier neurophysiological correlate of holistic processing in the P1 component. This contrasts with the absence of group effects of the P1 component in the present study. As Chen et al. (2013) had examined holistic processing to Chinese characters in adults, the discrepancy to the present findings indicating holistic processing of faces in children is difficult to account for. Future developmental studies might track the trajectory of neural mechanisms to holistic processing in words and faces.

4.2 | The script system hypothesis

The present findings support the script system hypothesis we proposed. Enhanced N170 negativity is generally taken to reflect higher visual expertise for certain stimuli (Tanaka & Curran, 2001), which in many cases goes along with more pronounced configural perception (e.g., Gauthier et al., 2003; Rossion et al., 2002). Accordingly, the enhanced N170 in Chinese children suggests that they show more expertise in perceiving visual stimulus configurations. This suggestion is also supported by their performance in the one-back task, where Chinese children were faster than German children without loss of accuracy. Chinese characters have many similarities with faces (Liu et al., 2009) and their complex spatial configurations bias Chinese readers toward holistic processing during reading acquisition as compared to alphabetic readers (e.g., Ben-Yehudah et al., 2019; Demetriou et al., 2005). Thus, the larger N170 to both naturalistic and Mooney faces in Chinese children, indicating more pronounced holistic face processing, might be ascribed to a positive transfer to face processing from their extensive training in holistic visual processing provided by reading acquisition in Chinese.

However, in explaining the group differences in holistic face processing one should also consider an alternative account, that it might be due to the suppression of holistic processing following the reading acquisition of alphabetic

languages. Alphabetic readers have been demonstrated to prefer analytic orthographic coding (e.g., Ben-Yehudah et al., 2019). Portuguese illiterates showed more holistic processing of both face and house stimuli than Portuguese literates, suggesting that literacy in alphabetic languages may diminish holistic processing skills (Ventura et al., 2013). Thus, reading acquisition of alphabetic script involving extensive training of analytic processing might induce a generic shift in the ability to deploy analytic visual processing on face processing, resulting in less holistic processing in alphabetic readers than Chinese readers. Although we cannot with certainty distinguish between these two accounts, our results clearly demonstrate a superiority of Chinese children in holistic face processing compared to German children after about one year of formal reading acquisition. Future longitudinal studies starting at preschool age could be conducted to investigate the positive or the negative effects of acquiring different reading systems on holistic visual processing.

The script system account would be supported by correlations between literacy skills and face-elicited ERPs. We calculated Pearson correlations to measure the association of reading skills and N170 amplitudes to faces and Mooney faces in German and Chinese children separately. In general, the correlations were negative, hence in the direction of better reading skills being associated with larger (more negative) N170 amplitudes. However, all correlations were small (all r s < .30) and not significant in either group (all p s > .05). It is worth noting, however, that compared to the very small correlations in German children (all r s < .21), Chinese children showed a close to moderate negative correlation ($r = -.29$) between reading speed (1-minute reading score) and N170 amplitude to Mooney faces in the right hemisphere. Hence, although the observed correlations did not provide conclusive evidence for the script system account, this may be due to the small sample size and it may be premature to ignore the multiple tendencies toward an association. Thus, future studies could further examine the correlations between reading abilities and ERPs with larger samples.

Interestingly, our results in the adaptation task are at variance with a behavioral finding that Chinese and Japanese participants (logographic readers) were better in detecting differences in second-order relations than American participants (alphabetic readers) (Miyamoto et al., 2011). The inconsistency might be due to participants' age, children in the present study versus adults in the experiment of Miyamoto et al. (2011). Developmental studies indicate that the ability to process second-order relations improves at least until age 10 (e.g., Baudouin et al., 2010; Mondloch et al., 2002, 2004). Consequently, German and Chinese children aged 7–8 years, as investigated in the present study may have still immature

sensitivity to second-order relations and show different developmental trajectories, leading to contrarian results at different ages. Future developmental studies could track the developmental trajectory of sensitivity to second-order relations in different script readers.

4.3 | Brain accommodation to specific visual demands of Chinese and alphabetic scripts

We found enhanced N170 responses to faces and Mooney faces over visual occipitotemporal regions in Chinese children as compared to German children, apparently reflecting a flexible accommodation (Perfetti et al., 2007) or recycling (Dehaene & Cohen, 2007) of the visual system to the differential challenges posed by the two script systems studied in the present experiments. According to the accommodation hypothesis, the differences between readers of the two script systems may reflect how the brain optimizes visual processing by accommodating specific properties of the script systems (Perfetti et al., 2007). The neural recycling hypothesis suggested that reading relies on using pre-existing neural systems for vision, which may be employed (“recycled”) for the specific problems posed by reading (Dehaene & Cohen, 2007). Pre-existing visual processing skills involved in the processing of other non-verbal visual stimuli are overlearned with extensive training during reading acquisition and, in turn, induce structural and functional changes in the corresponding brain areas (see a review, Dehaene et al., 2015). Thus, differential visual processing skills required for Chinese and alphabetic reading are accompanied by different neurocognitive accommodation processes, and therefore learning to read different script systems can induce differences in visual processing.

More specifically, the present results indicate that the tuning of the neurocognitive system toward holistic processing is more pronounced by reading acquisition of the Chinese script system than an alphabetic script system. Reading Chinese appears to bias the neurocognitive system toward the holistic spatial analysis of Chinese characters due to their complex and usually square-shaped spatial configurations (e.g., Ben-Yehudah et al., 2019; Kao et al., 2010; Wang et al., 2011). As a result, because Chinese children are massively exposed to Chinese characters during reading acquisition, the accumulation of holistic visual processing expertise might in turn increasingly tune the children’s visual system toward holistic processing, resulting in enhanced N170 to both naturalistic and Mooney faces in Chinese children as compared with German children.

4.4 | Limitations and perspectives

Our study has several potential limitations. First, as in many cross-cultural studies on young participants, it is challenging to ascertain the equivalence of testing situations and equipment. The testing environment was not perfectly matched between German and Chinese children. Our Chinese children were tested in their school where lighting conditions were more difficult to control and less standardized than for the German children who were tested in an EEG lab. However, our group differences in N170 amplitude were condition-specific and not global as one would expect if due to differences in testing condition (e.g., Johannes et al., 1995).

Second, the results of this study are limited by somewhat incomplete matching of the groups. The Chinese group had received significantly longer formal education duration than German children, although the difference was only 1.5 months. On the other hand, the group differences in N170 amplitudes to faces cannot be explained by differences in education duration as there were no significant correlations between education duration and face N170 amplitudes in the German ($r = -.021, p > .05$) or Chinese ($r = .116, p > .05$) group. The socioeconomic background (SES) between German and Chinese groups was also not matched. The Chinese children were recruited from a primary school in a rural area, whereas German children were recruited from an urban area (Berlin). Thus, our Chinese children may have lower SES than our German children. However, participants with higher SES may show better performance in face-related tasks and greater activation in face-related regions than those with lower SES (Noble et al., 2007; Rosen et al., 2018). Therefore, our results point in the opposite direction with Chinese children performing better and showing larger face N170 amplitudes than German children, arguing against an SES account.

Third, as a control for stimulus-unspecific group differences, we used a one-back task with doodles, that is, complex visual stimuli without clear configural information. As the N170 component for doodles was very small and ambiguous, we refrained from analyzing these results. Therefore, although the second-order relationship task indicates that our group effects are stimulus-specific, future studies should seek rigorous control conditions for non-face-related visual processing.

Fourth, we cross-sectionally compared groups at only one specific time point of development. In a longitudinal study using a composite paradigm, Tso et al. (2012) reported that the holistic processing of Chinese characters decreased across grades one to five. Thus, it needs to be explored whether our findings in 7–8 years old children generalize to other age groups and adults. Hence, a more

direct proof of the script system hypothesis should use a longitudinal design, starting at preschool age, where group differences should still be absent.

Fifth, Chinese children in the present study learned the simplified Chinese script. Simplified Chinese script is visually less complex than traditional Chinese script, and the reading acquisition of the two scripts has been demonstrated to impose differential visual demands (Liu et al., 2016; McBride-Chang et al., 2005; Peng et al., 2010). Future studies may examine the differences between traditional Chinese readers and alphabetic readers on face processing.

Sixth, the Chinese children had also learned an alphabetic script, that is, Pinyin. It is possible that the reading acquisition of both Pinyin and Chinese script affect holistic face processing more than the effect of one script system alone; however, in the present study we cannot separate the effects of these two factors. As Pinyin is taught only as an aid to formal Chinese reading (Li & Ping, 2010), its mastery does not constitute formal reading of Chinese itself. Even if the ERP differences observed here would be due to learning Chinese script plus Pinyin versus just alphabetic script, they would still indicate that the reading acquisition experience can shape face processing and, specifically, holistic face processing.

Finally, the visual complexity of the script symbols may not be the only language factor affecting face processing. Across alphabetic languages, spelling-to-sound consistency (i.e., transparency) varies strongly and is a critical factor for reading acquisition (e.g., Ziegler & Goswami, 2005). Thus, future studies could be carried out to examine the effects of orthographic transparency on face processing by comparing children who acquire more or less transparent orthographies, for example, German versus English.

5 | CONCLUSIONS

The present study provides the first direct evidence that Chinese children show larger face-related N170 amplitudes than German children. A similar difference in the N170 amplitude to Mooney faces but indistinguishable effects of second-order relationship adaptation indicate that the N170 differences specifically related to the superiority of Chinese children in holistic face processing. We suggest that this is due to the specific demands placed on the visual and mnemonic processing in different script systems learned by the Children. Specifically, the present findings support the notion that learning a logographic script system may have generalized neurocognitive consequences by strengthening holistic visual processing to suitable stimuli also in a non-linguistic domain.

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AUTHOR CONTRIBUTIONS

Xiaoli Ma: Conceptualization; data curation; formal analysis; investigation; methodology; software; visualization; writing – original draft; writing – review and editing. **Jing Kang:** Formal analysis; investigation; software. **Xinran Li:** Formal analysis; investigation. **Urs Maurer:** Writing – review and editing. **Xiaohua Cao:** Conceptualization; funding acquisition; resources. **Werner Sommer:** Conceptualization; funding acquisition; methodology; project administration; resources; supervision; writing – review and editing.

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

ORCID

Xiaoli Ma  <https://orcid.org/0000-0002-2335-9812>

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

FIGURE S1 Grand average ERPs to naturalistic faces in different filter settings for German and Chinese children. (a) high-pass filtered ERP (2–30) Hz and (b) Broad-band ERP (0.1–30 Hz)

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