Event-related potential evidence in Chinese children: Type of literacy training modulates neural orthographic sensitivity

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Abstract
Visual word N170 is an index of perceptual expertise for visual words across different writing systems. Recent developmental studies have shown the early emergence of visual word N170 and its close association with individual’s reading ability. In the current study, we investigated whether fine-tuning N170 for Chinese characters could emerge after short-term literacy learning in young pre-literate children. Two groups of Chinese preschool children were trained for visual identification and free writing respectively. Results showed that visual identification learning led to enhanced N170 sensitivity to characters over radical-combinations in the left hemisphere and line-combinations in the right hemisphere, and writing learning led to enhanced N170 sensitivity to characters over radical-combinations and line-combinations in the right hemisphere. These results suggested that the N170 component became more sensitive for the local graphic feature (strokes) of characters rapidly after brief literacy learning even in young children; and writing learning experiences specifically led to enhanced orthographic sensitivity in the right hemisphere.

Keywords
N170, fine-tuning, training, Chinese characters, writing, children

Introduction
Visual word N170, a generic index of perceptual expertise for various writing systems, is found to be highly sensitive for visual words over non-word stimuli (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Peronnet, 1999; Cao, Li, Zhao, & Weng, 2011; Li, Lee, Zhao, Yang, He, & Weng, 2013; Lin, Chen, Zhao, Li, He, & Weng, 2011; Liu & Perfetti, 2003; Maurer, Brandeis, & McCandliss, 2005a; Maurer et al., 2006). The word-specific N170 occurred within 200 milliseconds (ms) of stimulus onset and the amplitude of N170 for words in the left hemisphere was larger than that for non-word stimuli (Bentin et al., 1999; Brem et al., 2006; Brem, Halder, Bucher, Summers, Martin, & Brandeis, 2009; Maurer et al., 2005a; Zhao, Li, Lin, Cao, He, & Weng, 2012). Developmental studies have established that word-specific N170 emerged rapidly once children were taught to read, and showed a coarse tuning effect for words over non-print control stimuli (Cao et al., 2011; Maurer et al., 2006). Specifically, in no more than two years after children began to read, a more negative N170 component was elicited for words than for line drawings (Cao et al., 2011), symbols (Maurer et al., 2006; Zhao et al., 2014), and false fonts (Eberhard-Moscicka, Jost, Raith, & Maurer, 2015). Eberhard-Moscicka et al. (2015) further found that the N170 tuning effect for words was associated with children’s vocabulary. Notably, recent studies have established that even in preschool children, the coarse N170 tuning for print can emerge rapidly after a short-term training for literacy (Brem et al., 2010; Zhao, Li, Zhao, Gaspar, & Weng, 2015).

In addition to the coarse N170 tuning for print, in skilled readers, the N170 component also showed sensitivity for words over pseudo-words in English (McCandliss, Posner, & Givon, 1997), and for characters over false characters and stroke combinations in Chinese (Lin et al., 2011; Zhao et al., 2012). The development of this fine N170 tuning for print has been investigated as well. Posner and McCandliss (1999) found that from the age of 10 on, the N170 amplitude evoked by learned words was larger than that by novel words and consonant strings. Maurer and colleagues (2006) found a larger N170 component for words than for pseudo-words in 8-year-old German children (with 1.5 years of school training for reading), which suggested that the N170 was tuned to lexical information of visual words (the “lexical” effect). Recently, a study on younger German children with high reading ability (7 years old, with 6 months of training for reading) found that, though the N170 amplitude for words and for pseudo-words did not differ, the N170 amplitude for words was larger than that for consonant strings (Zhao et al., 2013). In Chinese children, after 1.5 years of literacy learning, the N170 tuning effect was observed in real and pseudo-characters relative to non-characters but no significant difference in N170 amplitude was observed between real characters and pseudo-characters (Tong et al., 2016). Thus, the fine N170 tuning for words (in terms of difference in amplitude between real words and non-words) may reflect the selectivity for orthographic regularity at least in the primary years of learning to read.
and was closely associated with children’s individual reading experience. While the coarse N170 tuning for print can emerge rapidly after a short-term literacy training in young and pre-literate children (Brem et al., 2010; Zhao et al., 2015), whether the fine N170 tuning for words could be observed as well after short-term literacy training in pre-literate children is still open. To our knowledge there is no study reported by now.

Visual-orthographic skills play an important role in learning Chinese in beginning readers (Siok & Fletcher, 2001; Tan, Spinks, Eden, Perfetti, & Siok, 2005; Yin & McBride, 2015). Consequently, in instruction of written Chinese, rote copying of characters is an essential way of learning to write characters (Tan et al., 2005; Tan, Xu, Chang, & Siok, 2013; Wu, Li, & Anderson, 1999). Also, copying skill was closely associated with reading ability in Children (McBride-Chang, Chung, & Tong, 2011; Wang & McBride, 2016). However, there was little evidence for the effect of writing experience on the emergence of visual word expertise N170 in Chinese children. The writing training effect on the N170 amplitude of Chinese characters was not as robust as that of visual identification after training in Zhao et al. (2015). The results can be interpreted that writing experience might affect the sensitivity to orthographic properties in Chinese characters that could not be probed with control stimuli of non-print types (e.g., faces and line-drawings in Zhao et al., 2015). Previous studies have found that, with more writing experience, the holistic processing of Chinese characters decreased in young Chinese learners. This finding indicated that, when learning to write, children became more sensitive to the internal constituent components of Chinese characters (Tso, Au, & Hsiao, 2012, 2014). Further, by training adults for whom Chinese was a second language to learn characters, Guan, Liu, Chan, Ye, and Perfetti (2011) found that writing practice uniquely strengthened orthography during learning Chinese characters (Guan et al., 2011). Thus, a possibility remains to be tested that writing experience would affect the neural sensitivity to more local features, such as the positions of radicals and of strokes in Chinese characters.

Therefore, the first aim of the current study is to investigate whether short-term literacy training in Chinese children would prompt the emergence of the fine N170 tuning for Chinese characters. In order to answer this question directly, we adopted a short-term training design (within 4 weeks). Secondly, the study was designed to probe the effect of writing training on the fine N170 tuning for Chinese characters. Two training conditions were designed: the visual identification learning condition; and the free writing learning condition. In order to control children’s pre-training literacy experience, all participants were tested with a Chinese word recognition test developed for preschoolers (Chow, McBride-Chang, Cheung, & Chow, 2008; Li et al., 2013). The maximum possible score of the test was 61. Children with scores less than 30 were selected as participants, and the mean score of the participants in the word recognition test was 5.45 (standard deviation ($SD$) = 6.43).

All the participants took a battery of tests to assess their reading ability, fine motor ability, visual motor integration ability, and non-verbal intelligence. Children’s fine-motor ability was assessed using a 24-hole pegboard in which children were instructed to insert 24 cylindrical pieces as fast as they could (Martzog, Chen, Stoeper, Shi, & Ziegler, 2012). The experimenter recorded the time (Mean time = 141.72 seconds, $SD$ = 30.98) and the hand used when children completed the test. The Visual-Motor Integration (VMI) subtest in Frostig’s Developmental Test of Visual Perception (Second Edition, DTVP-2) was used to assess children’s visual-motor integration ability (Mean score = 16.34, $SD$ = 3.88). Non-verbal intelligence test (Combined Raven’s Test (CRT), Chinese version, 1991) was administered (Mean intelligence quotient (IQ) = 104.67, $SD$ = 11.64). Children with normal IQ (IQ scores at or above 80) were assigned to either Visual Identification Learning (VL) or Free Writing (FW) condition with their age, gender, reading ability, fine motor ability, visual motor integration ability, and intelligence matched (all $p$-values > 0.50, for detailed results see Zhao et al., 2015). Out of the thirty-four children originally recruited, four were excluded because of low data quality (less than 20 valid trials for any stimulus type in either event-related potential (ERP) Pre- or Post-test) and one child refused to participate in the ERP.

**Methods**

**Participants**

Thirty-four preschool children were recruited from one kindergarten to participate in the study. All were native Mandarin speakers, and had no formal reading training experience. They were all right-handed, without known neurological diseases or psychological disorders according to parents and teachers’ reports. All the procedures and protocols were approved by the Institutional Review Board of the Institute of Psychology, Chinese Academy of Sciences. All the parents were provided with full information about the study, were informed that their child was free to leave the study at any time and for any reasons, and gave informed consent. In order to control children’s pre-training literacy experience, all participants were tested with a Chinese word recognition test developed for preschoolers (Chow, McBride-Chang, Cheung, & Chow, 2008; Li et al., 2013). The maximum possible score of the test was 61. Children with scores less than 30 were selected as participants, and the mean score of the participants in the word recognition test was 5.45 (standard deviation ($SD$) = 6.43).

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Figure 1. Procedures and samples. (a) Schematic description of study design. Black blocks referred to the ERP experiment. White blocks referred to the behavior experiment. Gray blocks referred to the training sessions. (b) A sample page for the VL group. Children need to mark the same character (急) introduced by the experimenter during learning. (c) A sample page for the FW group. Children need to trace the gray character (急) and copy it twice in the boxes below within the time limit. (d) Procedure of ERP experiment. Red pictures were targets. Children were instructed to attend to the stimuli and press a key on seeing the targets. (e) Stimulus samples in the ERP experiment. Stimulus from the left: Real Chinese character, Radical-combination, Stroke-combination, and Line-combination.

A total of 29 children (13 in VL group and 16 in FW group; 17 females, Mean age = 58 months, SD = 3.32, age range = 48 to 69 months in the pretest session) completed all the experiments and their data were analyzed.

Stimuli and training

Twelve high frequency compound Chinese characters were selected as learning materials. Each character was composed of 3 simple radicals with a total number of strokes not more than 10 (for example, 急, 帮, 荷, 夜, 帮) to make the structure and the visual complexity of these 12 characters comparable. None of the participants reported knowing these characters before the training started.

The training sessions started one week after the Pre-test session and were carried out once a week in the upcoming four weeks (Figure 1(a)). Children in groups of four to five took part in the training sessions together. At the beginning of each session, the experimenter showed a sample character and instructed children to go through the learning procedure as a warm-up. The formal training would start only if all the children in the small group understood the learning procedure. For each training session, all the learning materials were learned twice in different orders each time. Altogether, including the warm-up and a short break within one session, each training session took around 30 minutes within which the actual training time was 25 minutes. The two groups of children needed to take part in four training sessions (1 training session per week) in the training period and spend a total training time of about 100 minutes.

During a training session, the experimenter presented a character which was written on a card to children while telling them the pronunciation and meaning of the character. Next, children in the VL group needed to identify the character from 8 different characters printed on a sheet of paper (Figure 1(b)) after verbally repeating the character and its meaning. For each character, they could practice 4 times on 4 different sheets. Children in the FW group were also presented with the character first but it was printed in gray at the top of the sheet (Figure 1(c)). Children were instructed to trace over the gray character with pencil after orally repeating the character and its meaning. Then, they could copy the character twice below the sample character on the same page. Specifically, in order to match the exposure time for each child, we limited the exposure time to each character to two minutes in each training session for both groups.

Experiments

In order to measure the training effect at both behavioral and neural levels, children in both groups took part in the behavior and ERP experiments the first time before training and again one week after the last training session. The experimental procedures in the Pre-test and Post-test were similar. The statistics analysis was performed with SPSS 17.0.

Behavioral experiment. Before and after training, a computerized lexical decision task was adopted to examine children’s orthographic knowledge about visual words. Four types of stimuli were tested in this task: Chinese characters (Character); radical-combinations (Radical); stroke-combinations (Stroke); and line-combinations (Line). Stimuli in the Chinese character condition were the same 12 characters in the training sessions. Radical-combinations were constructed by randomly changing the radicals’ positions to illegal positions based on the real character. Stroke-combinations were constructed by randomly re-arranging strokes based on the radical-combinations. Line-combinations were formed by replacing the strokes with straight lines in the stroke-combinations. Each type of stimuli included 12 items. E-prime software (Version 2.0) was used to present the stimuli. The full experiment contained 96 trials with each stimulus presented twice in random order. For each trial, one stimulus was presented in black in the center of the screen against a white background. Children were instructed to judge whether the stimuli were a real character or not. The experimenter would not proceed to the next trial until the child responded orally. Correct response was defined as judging character as “a real character” or non-character as “not a real character”. According to previous research (e.g., Zhao & Li, 2014), for each stimulus, only the judgment for its first presence was counted in calculating the accuracy on each type of stimuli.

ERP experiment

Stimuli and procedure. The ERP Stimuli were the same as in the behavioral experiment. For the ERP experiment, each stimulus type was presented in four colors: red; green; blue; and yellow. Thus, there were 48 different items for each stimulus type and 12 items in each color. The size of each stimulus was 91×90 pixels. The stimuli were presented with E-prime software (Version 2.0). During the experiment, the stimuli were presented against a gray background subtending a vertical visual angle of 1.38° and a horizontal visual angle of 1.36° from the participants’ eyes, who sat 100 cm away from the screen. For each trial, a stimulus in one of the four colors was presented for 300 ms, followed by a jittered interval of 1500–1800 ms of gray screen (see Figure 1(d)). Stimuli of the four stimulus types in four different colors were mixed and were presented in random order. Children were instructed to attend...
to the pictures on the screen and respond on seeing the red pictures (targets) by pressing one specified key on the keyboard as quickly and accurately as possible (for detailed descriptions, see Zhao et al., 2015). Each participant had 5 runs in the ERP experiment. In each run, there were 5 target trials on average (the number of target trials was randomized from 3 to 6 in each run). Altogether, there were 5 targets in each stimulus type. All the participants performed well in the target detection task. Before training, the mean accuracy was 0.95 ($SD = 0.06$) and the mean response time was 447.00 ms ($SD = 87.6$). After training, the mean accuracy was 0.99 ($SD = 0.02$) and the mean response time was 419.21 ms ($SD = 84.34$).

Data recording and processing. Electroencephalogram (EEG) was recorded with a 32-channel Ag/AgCl elastic cap according to the extended 10–20 international system (NeuroScan Inc., El Paso, TX, USA). Bilateral mastoids served as an online reference, and the data were offline referenced to an average reference for subsequent analysis. An electrode between FPz and Fz served as ground. The horizontal electrooculography (EOG) and the vertical EOG were recorded according to the previous study (Li et al., 2013). Electrode impedances were kept below 5kΩ. Data sampled at 1000 Hz were filtered with a band pass on-line filter from 0.1 to 100 Hz and the 50 Hz noise was notched for all channels.

Eye blinks were first corrected with Neuroscan 4.5 software. EEG data were then digitally band-pass filtered (0.5–30 Hz) and were epoched from -100 ms to 800 ms, and corrected by the baseline correction (-100 ms to 0 ms). Data from 5 children in Pre-test and 5 children in Post-test had excessive linear drifts and were corrected with linear detrend and baseline correction was applied again afterwards. Artifacts exceeding ±100 µV in the channels of interest were automatically rejected (because of higher noise level, this criterion was broadened to ±125 µV for 7 children’s data in both Pre- and Post-test, and ±150 µV for 1 child’s data to keep an acceptable number of trials). Then, EEG signals of non-target trials were averaged to derive ERPs for characters, radical-combinations, stroke-combinations and line-combinations respectively and grand averages were calculated for all the four conditions of interest. ERP data from at least 20 epochs were averaged for each stimulus type for each child (Pre-test: Mean epoch number = 32, $SD = 5$; Post-test: Mean epoch number = 34, $SD = 7$). For the 29 children, a similar number of epochs with each stimulus type went into analysis (Pre-test: $F(3, 84) = 0.42$; Post-test: $F(3, 84) = 0.78$, $p = 0.42$). The 20-epoch threshold can at least amplify the signal-to-noise ratio to 5, and equal or larger numbers of epochs have been used in previous studies (i.e., mean number of epochs = 35.4, range = 15–42 in Brem et al., 2010). Channels over the occipital-temporal area (e.g., Maurer et al., 2006; Cao et al., 2011) with the maximum negative amplitude (T5/T6) were selected according to the previous literature on children at similar age (Li et al., 2013; Maurer et al., 2006) and visual inspection of the individual waveforms in the present study. The time window of 150 ms–300 ms after stimulus onset was also determined in such a way. The minima amplitude values and their corresponding latencies were detected using automatic peak detection within the time window as the N170 component. The averaged N170 peak amplitudes were calculated for each stimulus type in Pre-test and Post-test respectively. In addition, the peak amplitude of P100 component was also detected using automatic peak detection between 100 ms and 150 ms at the T5/T6 channel. P100 component was usually considered to be related to the processing of basic visual features (Tarkiainen et al., 1999). Absence of significant difference in P100 amplitude among stimulus types suggested that these stimulus types were matched in terms of the basic visual features.

Results

Lexical Decision Test

Discrimination ability (d') to Chinese characters. According to the Signal Detection Theory, we first calculated the d’ index to measure children’s discrimination ability to characters ($d’ = Z_{Hit(characters)} - Z_{False Alarm(non-characters)}$). In order to examine the effect of different learning experience, an analysis of variance (ANOVA) of Time (Pre-/Post-test) and Training group (VL/FW group) factors was conducted. The results revealed that the main effect of Time was significant ($F(1, 27) = 41.43$, $p < 0.01$, partial $\eta^2 = 0.61$). The main effect of Time revealed that $d’$ was significantly increased after training in children as a whole ($p < 0.01$). The main effect of Training group was not significant ($F (1, 27) = 0.000$, $p = 0.995$). The interaction between Time and Training group was marginally significant ($F (1, 27) = 3.51$, $p = 0.07$, partial $\eta^2 = 0.05$) (Figure 2(a)).
Accuracy for judging non-character stimulus. As three non-character types of stimuli were used in the lexical decision task, the ability to correctly judge non-character stimuli as non-characters (correct rejection) can also be considered as an index of character discrimination ability. Thus, an ANOVA on accuracies of judging non-character stimulus types with the within-subject factors of Stimulus Type (Radical vs. Stroke vs. Line) × Time (Pre-test vs. Post-test) and the between-subject factor of Training group (VL vs. FW) was performed. The result (Figure 2(b)) revealed significant main effects of Stimulus Type ($F(2,78) = 17.41, p < 0.01, \eta^2 = 0.31$) and Time ($F(1,39) = 41.43, p < 0.01, \eta^2 = 0.61$). The interaction between Stimulus Type and Time ($F(2,54) = 8.43, p < 0.01, \eta^2 = 0.24$) and the interaction between Training group and Time were significant ($F(1,27) = 6.33, p = 0.02, \eta^2 = 0.19$). No other main effects or interactions were significant ($p > 0.10$).

Post-hoc test for the Stimulus Type × Time interaction revealed that the accuracies for all the three non-character stimulus types significantly increased after training (all $p < 0.05$). In order to further identify the differentiated changes in the two training groups, we compared the differences between Pre-test and Post-test for each non-character stimulus type in each group with Bonferroni adjustment. The result revealed that, the accuracies for line condition and stroke condition increased significantly in both groups ($p < 0.05$), but the accuracy for radical condition increased significantly only in VL group ($p < 0.01$) but not in the FW group ($p = 0.14$).

ERP results

N170 result. Two parts of analyses were performed on the N170 amplitudes to examine the N170 tuning effects for Chinese characters relative to the non-character stimulus types.

Pre-training results of two groups. In order to confirm if the two groups were in matched pre-training statuses, an ANOVA was performed on the Pre-test data with between-subject factor of Training group (VL vs. FW) and within-subject factors of Stimulus Type and Hemisphere.

The ANOVA revealed that none of the Group main effect ($F(1,27) = 0.67, p = 0.42$), Stimulus Type main effect ($F(3,81) = 1.44, p = 0.24$), Training Group × Stimulus Type interaction ($F(3,81) = 1.88, p = 0.10$) or Training Group × Stimulus Type × Hemisphere 3-way interaction ($F(3,81) = 0.68, p = 0.54$) was significant. No significant differences between groups were found in the Pre-test for any stimulus type in either hemisphere (Figure 3). The results of Pre-test indicated that, before training, the N170 amplitude elicited by characters was not different from that by any non-character stimulus type in either hemisphere for either group of children (Figure 4(a)).

Effects of visual learning and free writing. A repeated-measures ANOVA on the N170 amplitudes with between-subject factor of Training group and the within-subject factors of Time, Stimulus Type and Hemisphere was conducted. This analysis was conducted to compare the effect of different learning conditions on the N170 expertise for characters after training. The ANOVA revealed a significant main effect of Stimulus Type ($F(3,25) = 11.52, p < 0.01, \eta^2 = 0.58$).

Moreover, the 3-way interaction among Time × Group × Stimulus Type was significant ($F(3,25) = 3.14, p = 0.04, \eta^2 = 0.58$) and the interaction among Time × Group × Hemisphere was marginally significant ($F(3,25) = 3.66, p = 0.07, \eta^2 = 0.12$). None of other main effects or interactions were significant ($p > 0.10$). The two 3-way interactions indicated that, in the two groups, there could be differentiated changes in the N170 amplitude in response to each Stimulus Type and in each hemisphere after training. Thus, we further
examined the interactions among Training group, Time and Stimulus Type within each hemisphere respectively.

In the left hemisphere, the ANOVA with Training group, Time and Stimulus Type revealed only a significant main effect of Stimulus Type ($F(3,81) = 3.05, p = 0.04$, partial $\eta^2 = 0.10$). The N170 amplitude elicited by characters was larger than that by the line-combination ($p = 0.05$) and was marginally larger than that by the radical-combination ($p = 0.09$). None of the other main effects or interactions were significant ($p_s > 0.10$).

In order to examine the changes in the sensitivity of the N170 amplitude for characters over the other non-character types after training in the two groups, we further performed planned comparisons to compare the differences between character and non-character conditions both before and after training in two groups within the left hemisphere with Bonferroni adjustment. In the VL group, before training, there was no significant difference between the N170 amplitude in character condition and that in any non-character condition ($p_s > 0.50$) (Figure 5(a)), whereas after training, the N170 amplitude of character condition became larger than that of radical condition ($p = 0.02$) (Figure 5(c)). In the FW group, there was no significant difference between the N170 amplitude elicited by character and those by non-characters either before or after training ($p_s > 0.10$) (Figure 5(a) and (c)).

In the right hemisphere, the Stimulus Type main effect ($F(3,81) = 10.78, p < 0.01$, partial $\eta^2 = 0.29$) and the interaction between Time and Stimulus Type ($F(3,81) = 3.34, p = 0.04$, partial $\eta^2 = 0.11$) were significant. Before training, there were no significant differences among N170 amplitudes elicited by the four stimulus types ($p_s > 0.10$). After training, the N170 amplitude elicited by character became larger than those by the other three non-character ($p_s < 0.05$). Plus, the N170 amplitude in the stroke condition was larger than that in the line condition ($p = 0.02$). None of the other main effects or interactions were significant ($p_s > 0.10$).

Similar planned comparisons were conducted in the N170 amplitudes in the right hemisphere. The N170 amplitude elicited by characters was compared with those by the other non-character stimulus types in the two groups respectively both before and after training within the right hemisphere with Bonferroni adjustment. In the VL group, before training, there were no significant differences between the N170 amplitude elicited by characters and those by the other three non-character stimulus types ($p_s > 0.50$) (Figure 5(b)). After training, the N170 amplitude elicited by characters became larger than that by line-combinations ($p < 0.01$) (Figure 5(d)). In the FW group, before training, there were no significant differences between the N170 amplitude by character and those by the other three non-characters’ stimulus types ($p_s > 0.50$) (Figure 5(b)). After
training, the N170 amplitude elicited by character became larger than that by line \((p < 0.01)\) and was marginally larger than that by radical \((p = 0.052)\) (Figure 5(d)).

**N170 Peak latency.** The peak latency of N170 was subjected to an ANOVA with between-subject factors of Training Group and within-subject factors of Time (Pre- vs. Post-test), Stimulus Type (Character vs. Radical vs. Stroke vs. Line) and Hemisphere (Left vs. Right).

The ANOVA on the N170 peak latencies (Table 1) revealed that the main effect of Time was significant \((F(1,27) = 8.55, p < 0.01, \eta^2 = 0.24)\). The N170 peak latency in the Pre-test was shorter than that in the Post-test. The Training group × Hemisphere interaction was marginally significant \((F(1,27) = 3.25, p = 0.08, \eta^2 = 0.11)\). Only in the FW group, the N170 peak latency in the right hemisphere was shorter than that in the left hemisphere \((VL: p = 0.67; FW: p = 0.04)\). Other main effects or interactions were not significant \((ps > 0.10)\).

**P100 amplitude.** In order to examine if the post-training modulations in the pattern of sensitivity to stimulus types indexed by N170 amplitude were confounded by early basic visual feature processing, we performed an ANOVA on the P100 amplitude with between-subject factor of Training Group and within-subject factors of Time (Pre- vs. Post-test), Stimulus Type (Character vs. Radical vs. Stroke vs. Line) and Hemisphere (Left vs. Right).

The ANOVA for the P100 amplitude (Table 1) revealed that there were no significant differences among the characters and non-character stimulus types in either Pre- or Post-test (main effect of Stimulus Type: \(F(3,81) = 0.42, p = 0.70, \eta^2 = 0.02\); Stimulus Type × Time: \(F(3,81) = 1.30, p = 0.28, \eta^2 = 0.05\)). The main effect of Time was not significant \((F(1,27) = 0.46, p = 0.50)\) but the Training Group × Time interaction was significant \((F(1,27) = 4.36, p = 0.05, \eta^2 = 0.14)\). The difference between the P100 amplitude in the Pre-test and that in the Post-test was not significant \((p = 0.35)\) in the VL group, yet P100 amplitude was larger in the Post-test than Pre-test \((p = 0.05)\) in the FW group. Moreover, the main effect of Hemisphere was significant \((F(1,27) = 7.91, p < 0.01, \eta^2 = 0.23)\) and the Hemisphere × Time interaction was marginally significant \((F(1,27) = 3.05, p = 0.09, \eta^2 = 0.10)\). Before training, P100 amplitude in the right hemisphere was not different from that in the left hemisphere \((p = 0.11)\). After training, the P100 amplitude in the right hemisphere became larger than that in the left hemisphere \((p < 0.01)\). No other main effect or interactions were significant \((ps > 0.10)\). Results from P100 amplitude indicated that the training effect on the pattern of sensitivity to stimulus types indexed by N170 amplitude was not confounded by processing of early basic visual features.

**Discussion**

The current study examined the effects of short-term reading and writing training on the emergence of fine-tuning N170 for Chinese character in young children. In line with the previous findings in...
The N170 component in the right hemisphere became sensitive to characters relative to radical-combinations in both hemispheres. The N170 amplitude for characters was not significantly different from that for stroke-combinations. These results were consistent with the findings in the behavioral test. Children’s ability to judge line-combinations as non-characters was enhanced in both groups after the short-term literacy training. It indicated that after short-term learning, the N170 component became more sensitive to the local graphic feature (strokes) of Characters. In addition, a larger N170 amplitude was also found for character than for radical combination and line combination in the left hemisphere. These results are consistent with a recent study in young Chinese children, in which 7.7-year-old children showed larger N170 response to characters than to stroke combinations (Tong et al., 2016). Since the N170 tuning effect was associated with children’s reading ability, the fine-tuning effect we found in children of age five after a short-term literacy learning could be the starting point of the development of N170 tuning for orthographic properties of Chinese characters. The fine N170 tuning effect might further develop with more reading experience (Tong et al., 2016). However, the radical combination stimuli in the present study were formed by the radicals in illegal positions, which meant the combinations were non-characters instead of pseudo-characters. Therefore, the differences between character and non-characters in the current study could only reflect orthographic processing rather than the lexical effect. Whether the lexical effect of N170 could emerge early still needs further studies, which are to include pseudo-character as one type of stimulus.

The N170 component in the right hemisphere became sensitive to characters in comparison to line-combinations and radical-combinations after writing practice with Chinese characters in young children. In line with previous findings using the functional magnetic resonance imaging technique in preschool children and in adults learning artificial scripts (James, 2010; Longcamp et al., 2008), the current study showed that writing experience could enhance the brain activities associated with visual word processing. The sensitivity for characters over radical combinations was consistent with the behavioral evidence that writing experience could modulate holistic processing of Chinese characters in adults and school age children (Tso et al., 2012). As stated by Tan et al. (2005), the contribution of writing experience might be mediated by the orthographic awareness that was engaged by the analysis of internal structures of printed characters. With the ERP technique, our results further supported that at the early stage of visual word processing, the effect of writing training specifically led to sensitivity for...

### Table 1. Peak latency (ms) of N170 component at T5/T6 before and after training in VL group and FW group.

<table>
<thead>
<tr>
<th>Time</th>
<th>Training Group</th>
<th>Character</th>
<th>Radical</th>
<th>Stroke</th>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T5</td>
<td>T6</td>
<td>T5</td>
<td>T6</td>
</tr>
<tr>
<td>Pre-test</td>
<td>Visual Learning</td>
<td>208</td>
<td>215</td>
<td>209</td>
<td>207</td>
</tr>
<tr>
<td></td>
<td>(20)</td>
<td>(15)</td>
<td>(19)</td>
<td>(16)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Free Writing</td>
<td>223</td>
<td>211</td>
<td>220</td>
<td>205</td>
</tr>
<tr>
<td></td>
<td>(15)</td>
<td>(22)</td>
<td>(20)</td>
<td>(24)</td>
<td></td>
</tr>
<tr>
<td>Post-test</td>
<td>Visual Learning</td>
<td>211</td>
<td>221</td>
<td>217</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Free Writing</td>
<td>221</td>
<td>218</td>
<td>225</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>(21)</td>
<td>(20)</td>
<td>(25)</td>
<td>(26)</td>
<td></td>
</tr>
</tbody>
</table>

Note. Means of peak latency for each training group are listed in the table with the standard deviation for each group in each condition in parentheses.

### Table 2. Peak amplitude (µV) of P100 component at T5/T6 before and after training in VL group and FW group.

<table>
<thead>
<tr>
<th>Time</th>
<th>Training Group</th>
<th>Character</th>
<th>Radical</th>
<th>Stroke</th>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>T5</td>
<td>T6</td>
<td>T5</td>
<td>T6</td>
</tr>
<tr>
<td></td>
<td>(4.73)</td>
<td>(5.92)</td>
<td>(5.39)</td>
<td>(7.80)</td>
<td>(5.23)</td>
</tr>
<tr>
<td></td>
<td>Free Writing</td>
<td>10.42</td>
<td>13.56</td>
<td>9.57</td>
<td>13.77</td>
</tr>
<tr>
<td></td>
<td>(6.45)</td>
<td>(9.12)</td>
<td>(6.24)</td>
<td>(9.60)</td>
<td>(4.96)</td>
</tr>
<tr>
<td></td>
<td>Free Writing</td>
<td>11.81</td>
<td>16.87</td>
<td>9.96</td>
<td>18.57</td>
</tr>
<tr>
<td></td>
<td>(7.87)</td>
<td>(5.70)</td>
<td>(6.20)</td>
<td>(7.67)</td>
<td>(7.89)</td>
</tr>
</tbody>
</table>

Note. Mean amplitudes for each training group are listed in the table with the standard deviation for each group in each condition in parentheses.

preliterate children (Brem et al., 2010; Maurer et al., 2006; Zhao et al., 2015), we observed that with short-term literacy experience, the N170 became sensitive for characters over other character-like stimuli. The results showed that there were no P100 differences among characters and three types of non-character stimuli, which suggested that the N170 tuning effect emerged after training was not led by the basic visual features of stimuli, such as visual complexity (Tarkiainen et al., 1999). Thus, in addition to the coarse tuning for characters found in our previous work (Zhao et al., 2015), the current study further established that the fine N170 tuning for orthographic properties of prints emerged after short-term training even in preliterate children as young as five years old.

Specifically, after the short-term literacy training, the N170 component was sensitive to characters relative to radical-combinations in the left hemisphere and line-combinations in both hemispheres. The N170 amplitude for characters was not significantly different from that for stroke-combinations. These results were consistent with the findings in the behavioral test. Children’s ability to judge line-combinations as non-characters was enhanced in both groups after the short-term literacy training. It indicated that after short-term learning, the N170 component became more sensitive to the local graphic feature (strokes) of Characters. In addition, a larger N170 amplitude was also found for character than for radical combination and line combination in the left hemisphere. These results are consistent with a recent study in young Chinese children, in which 7.7-year-old children showed larger N170 response to characters than to stroke combinations (Tong et al., 2016). Since the N170 tuning effect was associated with children’s reading ability, the fine-tuning effect we found in children of age...
orthographic properties in Chinese characters possibly by improving the analytical processing of characters during writing.

Another result worth noticing was that the strongest training effects on sensitivity of N170 for character were found over the right hemisphere, especially in the free writing group, while in skilled readers, the amplitude of word-specialized N170 component was larger for words than for non-language stimuli over the left hemisphere instead (Bentin et al., 1999; Brem et al., 2006, 2009; Maurer et al., 2005b). However, consistent with the current result, there were findings from pre-school children learning an alphabetic language that the N170 amplitude showed an increasing trend for word than for symbol strings in the right hemisphere in children with higher letter knowledge (Maurer et al., 2005b). Tong et al. (2016) also found the bilateral N170 tuning effect in 7.7-year-old children, which suggested that the right hemisphere might be involved in visual processing of characters at early stage of learning to read. Similar to the right-lateralized fine N170 tuning effect, the P100 became right-lateralized after training. This indicated that the tuning effect might already have occurred in the early stage of word processing and been recruited in the occipital cortex over the right hemisphere (Maurer et al., 2006). However, the P100 tuning effect was much smaller as compared to the subsequent N170 tuning effect for characters. Taken together, the current right-lateralized N170 tuning effect reflected that the right hemisphere might play an important role in the early development of expertise in processing of visual words and this early-emerging right-lateralized N170 component might serve as a precursor for the mature left-lateralized N170 component for visual words (Zhao et al., 2015).

As the stimuli were exactly the same in the Pre- and Post-test sessions, the enhanced and more right-lateralized P100 that had been found in the writing training group might alternatively be attributed to an attentional effect. Previous studies have suggested that the P100 component was larger during a more perceptually demanding task (e.g., Mangun, Hopfinger, Kussmaul, Fletcher, & Heinze, 1997). Children were instructed to attend to constructing the strokes within a character when trained to write. This temporal structure of character production may be activated during later character processing (Parkinson, Dyson, & Khurana, 2010; Parkinson & Khurana, 2007), which possibly drove the attention to the local stroke structures rather than the whole character and increased the perceptual load for children.

Expertise in processing of visual words was an important aspect of brain functional specialization and was correlated with multiple experiences (reading and writing). The current study found that, in regard to the features that have been examined in the current study in young preliterate Chinese children, the N170 sensitivity for the local visual features of strokes in Chinese characters emerged the earliest. Moreover, the current findings underlined the role of the visual-motor integration for early literacy learning by identifying the effect of writing experience on the development of visual word processing. However, the limited sample size of the present study leads to reduced statistical power. And the heavy cognitive load of writing the complex Chinese characters may further weaken the effect size of writing training. Also, a control group that received no intervention should have been introduced to substantiate the current finding and directly address the specific effects of visual identification learning and writing learning. In addition, whether the short-term learning experience just leads to a quick yet temporary change or would produce a profound influence in visual word processing needs further exploration. Human development was driven by the complex dynamic systems that were constructed by the interactions among the intrinsic brain dynamics, the extended brain-behavior networks and developmental processes (Byrge, Sporns, & Smith, 2014). In addition to the effect of literacy experience at the early age, more work is required to illustrate how brain development interacts with varied behavioral experience across ages and to further look into the internal adjustment of the global neural connectivity in addition to the activation in a local brain area.

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