



Word recognition semantic processing defects in Chinese children with developmental dyslexia: An event-related potential study

Enguo Wang*, Guangya Zhou, Yanfeng Wang, Haiwei Huang, Yabin Hou, Jinping Liu

ABSTRACT

This study reports the neurophysiological and behavioral correlates of lexical decision processes in Chinese-speaking dyslexic and non-dyslexic readers in order to understand the neural basis of dyslexia. Eighteen dyslexic children (ages 12~14) and 18 matched control children were tested, and the event-related potentials (ERPs) to real words and pseudo-words were recorded simultaneously with behavioral measures. The results showed that both groups had significantly longer response time for the pseudo-words. Furthermore, overall performance (in terms of lower accuracy and longer response time) was significantly worse among the dyslexic group during the lexical decision task. The differences between the dyslexic and control groups were mainly in the N130, RP, N400, and P600 components. The results suggest that Chinese dyslexic children have semantic processing defects. From a time course point of view, the early stages of processing reflect the Chinese dyslexic children's morpheme integration and category sorting capacity deficiencies, while the middle stages show their semantic integration difficulties. The later stages of processing show that during semantic processing, decision-making is difficult among these children. Based on Chinese characters and phonetic system similarities, we suggest there are semantic processing defects in Chinese dyslexic children.

Key Words: Word, Pseudo-word, RP, N400, P600, Dyslexia

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Introduction

Dyslexia is a specific developmental disorder in learning to read, and is not the direct result of impairments in general intelligence, gross neurological deficits, uncorrected visual or auditory problems, emotional disturbances, or inadequate schooling (International Classification of Diseases, ICD-10, 2009). In western children whose first language is alphabetic, the rate of dyslexia is 5–10% (Sally & Witz, 1998), while this rate is supposed to be 4-8% in China (Stevenson *et al.*, 1982). Dyslexia is characterized by great difficulties in or very incomplete development of accurate and fluent word reading and/or spelling (Lyon *et al.*, 2003). Over the years, there has been

increasing evidence that dyslexic readers have impairments in several systems relevant to reading (Shaul, Arzouan & Goldstein, 2012). Many studies suggest that the main source of their word decoding deficits lies in the difficulties of the phonological system, which is responsible for the use of the sound structure of language to process written and spoken language (Snowling & Nation, 1997; Shaywitz, 1996; Leong, 1999). Other studies have pointed to impairments in the orthographic system (Shaul, Arzouan, & Goldstein, 2012).

Orthographic knowledge is related to the visual information of a word, specifically the letters that comprise lexical patterns and their order in a word, which contributes to spelling

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ability, as well as to the ability to identify the visual pattern of a word (Corcos & Willows, 1993; Wagner & Barker, 1994). Recently, attention has turned to understanding the neural basis of dyslexia and many studies have focused on brain activity differences between fluent readers and dyslexic readers. Taroyan & Nicolson, (2009) found that P4 (around 400 ms from stimulus onset) and P5 (around 500 ms) were significantly delayed and attenuated for the dyslexic group; Shaul, Arzouan, & Goldstein, (2012) examined the processing of words and pseudo-words in the two hemispheres among dyslexic as compared to fluent readers, using behavioral, and electrophysiological source estimation measures. The result showed that dyslexic readers showed overall less activity than fluent readers, mainly during late processing stages. Indeed, differences in the P200 and/or P300 components, as well as in the N400 component between typically developing readers and those with dyslexia have often been reported in relation to orthographic or phonological processing across languages (e.g., Bonte *et al.*, 2007; Breznitz & Meyler, 2003; Meyler & Breznitz, 2005; Spironelli & Angrilli, 2009).

Discovering the processing differences between real words and pseudo-words is important for understanding the reading disturbances in dyslexia. Reading pseudo-words requires phonological decoding, whereas reading regular or real words relies on the orthographic presentation of the visual form of the letters (Shaul, Arzouan, & Goldstein, 2012). There is a large body of evidence on problems encountered by dyslexic children in phonological awareness tasks including grapheme-to-phoneme conversion (Nicolson, Fawcett, & Dean, 1995). Max *et al.* (1993) suggested there are two types of dyslexia: phonological (difficulty with pseudo-words) and surface (difficulty with irregular words). Consequently, the lexical decision task (real word or pseudo-word) is a valuable diagnostic test. Compared to reading regular words, pseudo-word reading was found to increase the activation in several language areas such as the left inferior frontal gyrus and inferior temporal gyrus (Price *et al.*, 1996; Mechelli *et al.*, 2003). Compared to real words, Processing pseudo-words not only activated classical left hemisphere language areas, but also activated right hemisphere regions (Price *et al.*, 1996).

Historically, research on dyslexia has focused mainly on the English language. Mahé's (2013) found that the lack of N170 became

hallmark of an atypical brain specialization in developmental dyslexia. Schulte-Körne (2013) used three reading related ERPs: the N170, N400 and LPC and found that compared to control children, children with dyslexia showed deficits in all the investigated ERPs. However, English is a language with irregular orthography. It is different from the transparent languages, such as German or Italian whose mapping between graphemes and phonemes is straightforward. As different language system may cause the incongruent effects, some researcher (Wimmer *et al.*, 2002; Csepe *et al.*, 2003) used the similar lexical decision tasks and ERPs recording to explore the problems encountered by the German-speaking Dyslexia children or young adults whose first language was Hungarian. The finding suggests that the word/pseudo-word effects in German and Hungarian may be different from those in English and other languages in that the early component like P150 and N150 is different between the real and pseudo words and the orthographic processing of words and pseudo words does not really differ in a transparent language like Hungarian, at least not in adults. Chinese language uses a logo graphic writing system with basic orthographic units and Chinese characters are a special semantic language, which is very different from alphabetic languages. First, most Chinese characters consist of two parts: the one usually indicates meaning, while the other one usually indicates pronunciation. Second, some Chinese characters originate from ancient simple pictures in China. More than 80% of modern Chinese characters are phonetic compound characters and consist of sub-character components or radicals arranged under the orthographic rules. Therefore, it is often stated that the use of phonological information may not be as critical when reading Chinese as it is when reading alphabetic languages (Ho, Chan, Lee, Tsang, & Luan, 2004; Shu, McBride-Chang, Wu, & Liu, 2006). Several behavioral studies demonstrated that Chinese dyslexic children have deficits in processing both the phonological and orthographic elements when reading Chinese characters (Shu *et al.*, 2006, 2005; Lv, & Wang, 2012). Therefore, Chinese dyslexia may have different neurological mechanisms from the dyslexia in other languages. Based on studies of Chinese individuals with dyslexia, Weekes *et al.* (1997) proposed a model of the lexical processing of Chinese characters.

When examining the semantic processing of dyslexic children, the most commonly used ERP

indicators are the recognition potential (RP), N400, and P600 components. The morphological identification of familiar words induces a peak in the range of 200–250 ms in the positive wave, and this component is called the RP. In addition to the importance of the RP in shape recognition, the consistency of its response with the expected stimulus is also important (Rudel & Hu, 2000). The N400 component was first described by Kutas and Hillyard (1980) and is generally considered to reflect an early stage of processing and the semantic integration of relevant information. Subsequently, many studies found that the N400 effect could not only be elicited by the processing of sentence but also by the processing of real and pseudo words. (Shu, Bai, Han, & Bi, 2003; Kuperberg, 2007; Maganioti, Hountala, & Papageorgiou, 2010; Kim & Sikos, 2011; Kutas & Federmeier, 2011; Schacht, Sommer, & Shmuilovich, 2014). The P600 was first discovered by Osterhout and Holcomb (1992). It was initially thought that the P600 component showed specific wave abnormalities during syntactic processing, which reflects the process of syntactic reanalysis. However, in recent years, some studies have found that semantic violations within a sentence can lead to a P600 effect (Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; Kolk, Chwilla, van Herten, & Oor, 2003; Hoeks, Stowe, & Doedens, 2004). After this phenomenon was found, it prompted researchers to re-interpret the meaning of the P600. Although, N400 effects in Chinese dyslexic children have been reported, most of these studies (Zhou, Meng, & Chen, 2002) adopted the ambiguous sentences as stimuli. It may need a further discussion about whether the N400 effects would still exist when the Chinese two character words are used as the experimental materials. Meanwhile, the semantic processing of Chinese dyslexic children and normal children in terms of the RP and P600 are unknown. Are Chinese words with phonetic recognition processed along similar time courses in both groups of children? Solving these problems requires more research on Chinese semantic processing. Examining differences in language processing between children with dyslexia and normal children may help reveal the different types of defects exhibited by children with dyslexia.

We aimed to study the time course and between-group variations in different stages of word/pseudo-word processing, lexical decision making, and response choice in Chinese-speaking dyslexics and controls by recording ERPs and

behavioral measures such as response time (RT) and response accuracy. Studying the time course of semantic processing using ERPs is a very effective research method, as ERPs can provide the precise timing of various processes. We predicted that if semantic processing defects were present in Chinese dyslexic children, then the ERP components to true words and false words presented during the word recognition task would differ between normal children and dyslexic children. If semantic processing defects appeared in Chinese dyslexic children only during the early stages of processing, then the ERP components N1 and RP would appear abnormal. However, if the semantic processing defects were in the later stages of processing, then the N400 and P600 components would show abnormalities.

However most of the previous studies were concerned with the alphabetic language such as English, little research is related to the Chinese language. Of these researches studying Chinese language, most of them adopted the sentence as the experimental materials. The linguistic features of Chinese are greatly different from the other alphabetic languages. Chinese, originated from the ancient hieroglyphic, is a relatively semantically transparent language. Their compounds characters each of which represents the smallest unit of meaning (i.e., morpheme) are typically composed of two different parts, a phonetic radical and a semantic radical. The phonetic radical provides cues of the sound of the character. However, this information is unreliable relative to the phonological cues provided by alphabetic orthographies (Shu, H., & Anderson, R. C. 1997). Another conspicuous difference between Chinese and alphabetic language in relation to the orthography features is that Chinese is visually more complicated than alphabetic language. There are only 26 letters in English but about 620 stroke patterns that make up Chinese characters. In contrast, the semantic radical indicates a character's meaning but not sound, distinguishing morphological from phonological information in a way that does not usually occur in alphabetic languages (Shu, H, 2006). Last but not least, the pronunciation of a Chinese character may be obtained either directly from the phonetic radical (e.g., deriving the sound of 码[ma] "yard" from its phonetic 马[ma]) or indirectly from making an analogy with another character owing the same phonetic radical (e.g., associating the sound of 码[ma] "yard" with that of 蚂[ma] "ant"). The former is similar to the regularity effect in English, while the latter reflects a consistency effect (Ho, C. S.,

2007). In general, although Chinese shared some similarities with other language systems, it also has its own features differing in orthography, pronunciation, morpheme and grammar. The study will not only extend our knowledge on the semantic processing of Chinese dyslexia but also help us reveal EPR related difference caused by different language system among dyslexia.

Methods

Participants

Thirty-eight preadolescence participated in this study (19 normal controls, 19 dyslexic children) and they were screened from several primary schools in Kaifeng. Based on the International Classification of Diseases (ICD-10, 2009), none of the participants had a *history of neurological, emotional, or psychiatric disorders, including attention deficit hyperactivity disorder (ADHD)*, and their associated medications. All of the participants were right-handed and had normal hearing and normal or corrected-to-normal vision. All participants had normal intelligence, with an overall intelligence quotient score of 85 or above, and received sufficient learning opportunities. The age range of all preadolescence participants was 12-14 years (mean age 12.8 years). The dyslexic children were selected according to a number of tests: vocabulary size, reading fluency, and Raven's Standard Progressive Matrices tests (see also Shu *et al.*, 2006). The criteria for selecting dyslexic children were that their scores on the vocabulary and reading fluency test had to be at least one standard deviation below the scores of other participants in the same grade. The parents of all participants provided their informed consent and participants were paid for their participation after the experiment. Preliminary analysis of the data showed that the number of correct responses in one participant was too low (below 50%), while artifacts in another participant were too high; therefore, we removed these two participants from further statistical analyses. Thus, 36 participants were included in the final analyses. Table 1 shows the average scores on the three tests for the two groups of participants.

Materials

The experiments consisted of lexical decision tasks that used Chinese two-character words including both the real words and pseudo-words as stimuli. ERPs were recorded during the tasks to determine differences between the waveforms and response accuracies to real and pseudo-

words. The dummy words, or pseudo-words, were composed of two characters (e.g., 片月: tablets, months), which separately constituted meaningful characters, but when combined had no specific or real meaning in Chinese. The formal experiment consisted of 200 two-character Chinese words (100 real words and 100 pseudo-words). The stimuli selected as the high frequency words were screened using the "Modern Chinese Frequency Dictionary". These two sets of stimuli were matched for word frequency, the number of strokes, and other factors.

A list of the complete stimuli is shown in the appendix.

Procedures

Stimuli were presented using the program E-Prime 2.0 (Psychology Software Tools Inc., Sharpsburg, PA, USA), with a display resolution of 1024 × 768 pixels. Stimuli were presented in white on a black background. There were 100 stimuli in each of the two-character word categories, i.e., words (e.g., 工作: work) and pseudo-words (e.g., 片月: tablets, month). Words from the two stimulus categories were randomly presented in each trial. A fixation cross (+) was presented first for 200 ms, followed by a 400–1000 ms blank screen which was presented at random intervals, and then the stimulus was presented for 1000 ms. When the stimulus appeared, participants were instructed to quickly determine whether it was a real word or pseudo-word by pressing a button. Specifically, participants were instructed to quickly and accurately press the "J" key on the keyboard with their right index finger when a real word appeared, or press the "F" key with their left forefinger when a pseudo-word appeared. There were two experimental blocks and each block contained 50 real words and 50 pseudo-words. Participants were permitted to rest at the end of the first block. In addition, before the beginning of the formal experiment, participants were familiarized with the task procedure and were asked to perform 21 trial exercises.

Electroencephalography (EEG) recording and data analyses

The EEG data were recorded and analyzed using the Brain-Product (BP-ERP; Gilching, Germany) workstation. EEGs were recorded from 32 electrodes based on the advanced International 10-20 system. The vertical electrooculograms (VEOGs) were recorded from electrodes placed above and below the right eye. The horizontal



EOGs (HEOGs) were recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. Scalp electrodes were referenced to an electrode on the tip of the nose and grounded to an electrode on the mastoid. Electrode impedance was kept below 5 kΩ. The EEGs were amplified (band pass 0.05-70 Hz) and digitized at a sampling rate of 500 Hz. The continuous EEG recordings were epoched off-line (-200 to 1000 ms), with the onset of the final word occurring at 0 ms.

The EEGs were averaged separately off-line for each condition. Any trials with EOG artifacts greater than ±75 μV were excluded from further analysis. Trial specific information, such as condition type (words, pseudo-words), accuracy

of responses, and mean RTs of correct responses, was recorded simultaneously with the EEG.

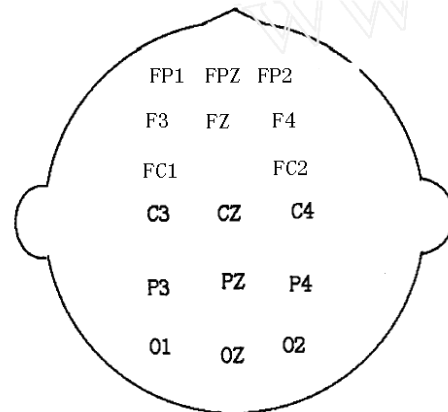


Figure 1. Electrode distribution

Table 1. Psychometric data of the dyslexic and control participants

	Controls (N = 18)		Dyslexics (N = 18)		F	P
	Mean	SD	Mean	SD		
Age	12.9	0.44	13.1	0.46	0.67	n.s.
Boys	10	0.72	11	0.67	0.36	n.s.
Girls	8	0.46	7	0.85	0.41	n.s.
IQ	106.4	3.32	104.7	4.67	1.89	n.s.
Vocabulary	3128	0.59	1848	5.28	169.8	0.0001
Reading fluency	64	0.89	35	4.36	153.4	0.0001

SD = standard deviation, n.s. = non-significant, IQ = intelligence quotient.

Table 2. Means and standard deviations for the behavioral measures

	Words		Pseudo-words	
	Controls	Dyslexics	Controls	Dyslexics
RT (ms)	594.61 ± 48.41	634.88 ± 67.02	674.79 ± 80.19	762.88 ± 123.97
Accuracy	0.93 ± 0.07	0.92 ± 0.03	0.92 ± 0.05	0.89 ± 0.05

RT = response time

Results

Behavioral data

The average response time was examined to eliminate the influence of outliers on response time and accuracy. As a result, we excluded any participants who showed RTs that were more or less than three standard deviations away from the mean response for both words and pseudo-words. Statistical analysis of the mean RTs revealed significant main effects of both group and word type. Specifically, the RTs were longer in dyslexics compared to controls [$F(1, 17) = 8.4, p < 0.01, \eta_p^2 = 0.29$], and were longer in the pseudo-word condition compared to the word condition [$F(1, 35) = 100.58, p < 0.001, \eta_p^2 = 0.79$]. There was a group by word type interaction for RT [$F(1, 35) = 27.34, p < 0.001, \eta_p^2 = 0.51$], and there was significantly delayed for the dyslexia group than for the control group. There were significant main

effects of group and word type on accuracy [$F(1, 17) = 7.6, p < 0.05, \eta_p^2 = 0.22$], in which dyslexic participants had a lower pseudo-word recognition accuracy compared to control participants. The mean RTs and accuracy for each group and condition are shown in Table 2.

Electrophysiological measures

The ERPs (average amplitude) of the dyslexia and control groups during the real word recognition task are shown in Figure 1 (control minus dyslexia). The ERPs (average amplitude) of the dyslexia and control groups during the pseudo-word recognition task are shown in Figure 2. Brain maps showing differences between the dyslexic and control groups during the word and pseudo-word recognition task are shown in Figure 3 and Figure 4.



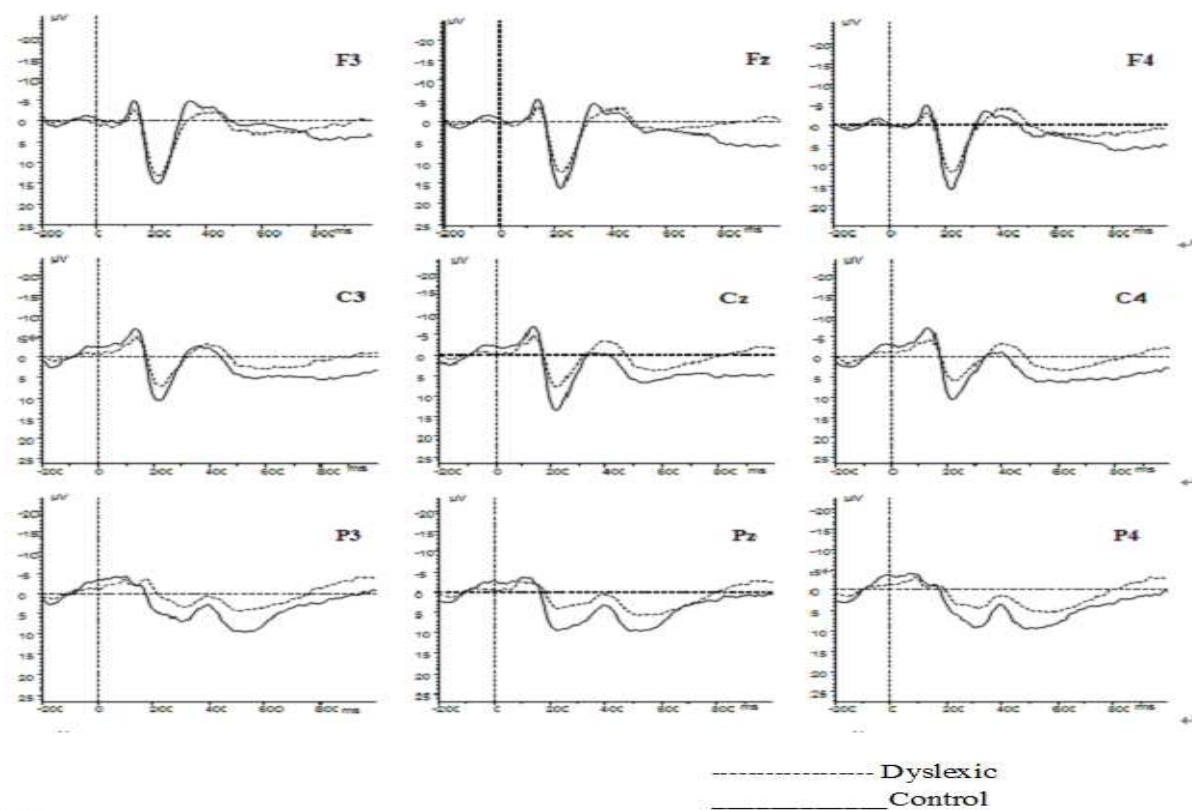


Figure 2. The average waves in dyslexic and control participants during the real word recognition task.

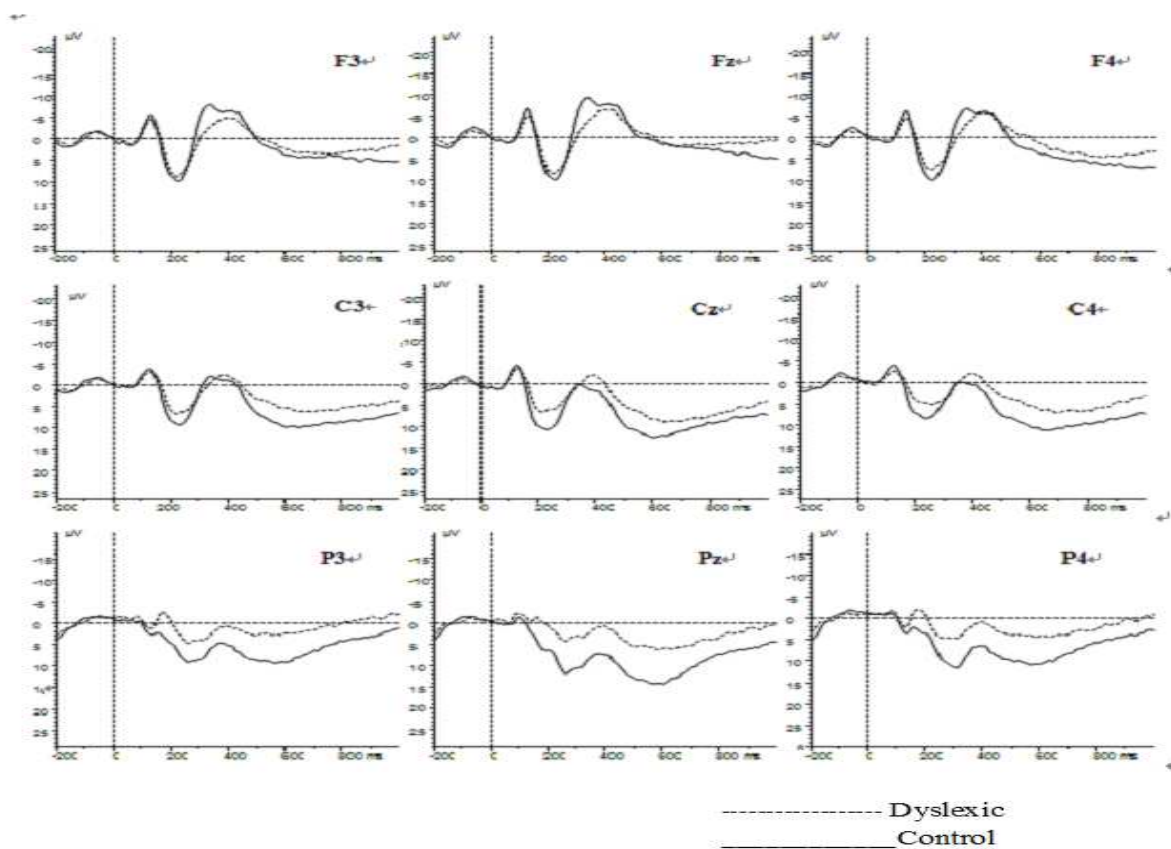


Figure 3. The average waves in dyslexic and control participants during the pseudo-word recognition task.

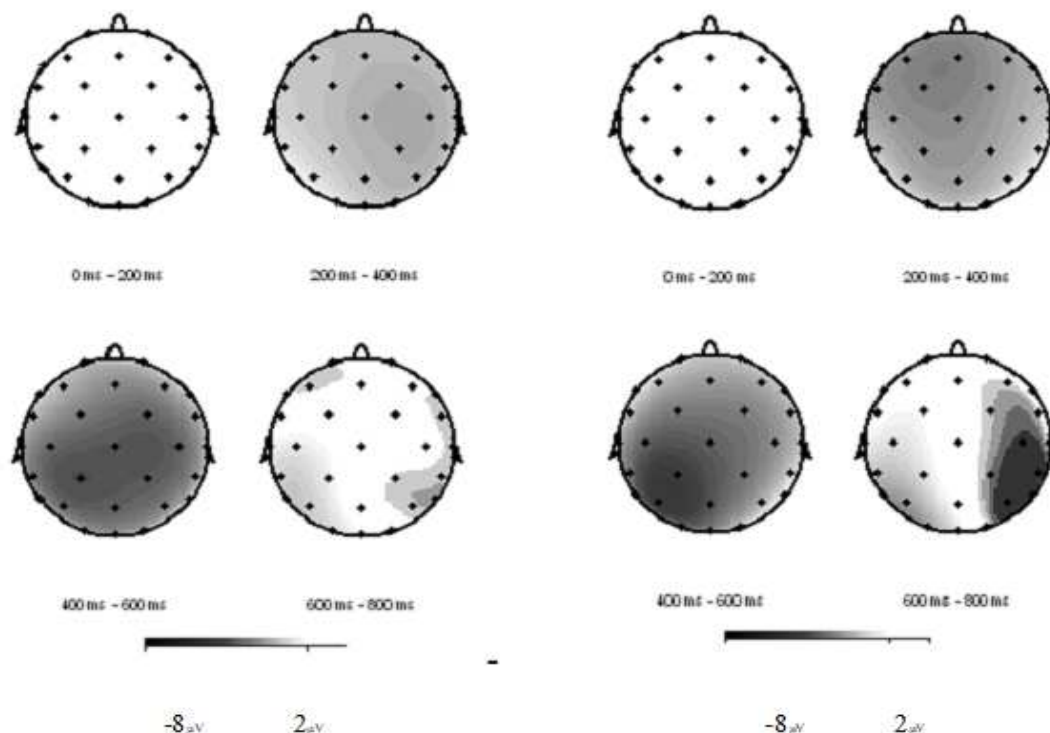


Figure 4. Brain maps showing differences between real word and pseudo-word recognition task in Dyslexics.

Figure 5. Brain maps showing differences between real word and pseudo-word recognition task in control.

In this study, the four components were included in the group average latency and amplitude 2 (word type) \times 3 levels (frontal, central, parietal) repeated measures analysis of variance (ANOVA). This study focuses on four time windows: 100~200 ms, 200~250 ms, 350~450 ms, and 500~700 ms. According to previous studies (Wang, *et al*, 2015), the mean amplitudes of each time window were subjected to repeated measures ANOVAs with the electrode position divided into four brain areas: frontal (F3, Fz, F4), central (C3, Cz, C4), and parietal (P3, Pz, P4).

100~200 ms time window (N130)

Results of the repeated measures ANOVA showed that there were no significant main effects of group and word type on amplitude. However, the latency of the N130 component was significantly different between the groups [$F(1, 34) = 7.45, p < 0.05, \eta_p^2=0.21$], and the latency in two word types was significantly longer in the dyslexia group than in the control group. There was a significant interaction effect of group and electrode position [$F(1, 34) = 8.31, p < 0.05, \eta_p^2=0.22$]. After further inspection, we found that the main difference between the groups was reflected in the P7, P3, and Pz3 electrodes in the left hemisphere.

200~250 ms time window (RP)

During the recognition of both words and pseudo-words, there was a main effect on the amplitude of group [$F(1, 34) = 9.38, p < 0.001, \eta_p^2=0.41$], in which control group showed larger amplitude than the dyscalculia group. There was a significant effect of word type [$F(1, 17) = 19.61, p < 0.001, \eta_p^2=0.58$], with the amplitudes of real word responses being greater in both groups than the amplitudes of pseudo-word responses.

The latency of the RP component was not significantly different in either group. For word type, the real words were significantly different compared to the pseudo-words, with the latency of pseudo-words being significantly delayed compared to words in both groups.

350~450 ms time window (N400)

Results of the repeated measures ANOVA showed there was a main effect on the amplitude of Group [$F(1, 34) = 14.29, p < 0.001, \eta_p^2=0.46$], in which dyscalculia group showed larger amplitude than the control group. Furthermore, the amplitude of the N400 component was significantly higher in both groups when recognizing pseudo-words compared to when recognizing real words [$F(1, 34) = 18.10, p < 0.001, \eta_p^2=0.49$]. The latency of the N400 component was significantly delayed for the dyslexia group than for the control group in identifying real words and pseudo-words [$F(1,$

34) = 12.09, $p < 0.01$, $\eta_p^2=0.38$]. In the dyslexia group, the latency of the N400 component was significantly delayed when identifying pseudo-words compared to when identifying real words [$F(1, 34) = 9.23$, $p < 0.05$, $\eta_p^2=0.24$]. There was also a significant group \times levels interaction effect [$F(1, 34) = 4.97$, $p < 0.05$, $\eta_p^2=0.21$]. Further simple effects analyses showed that the differences between the groups were mainly in the left hemisphere at the, T7, P7, and P3 electrode

500~700 ms time window (P600)

Results of the repeated measures ANOVA showed there was a main effect on the amplitude of Group [$F(1, 34) = 13.22$, $p < 0.01$, $\eta_p^2=0.43$], and the average amplitude of the P600 component was significantly higher in the control group than in the dyslexia group. There were differences in both groups between the word types, the amplitudes of the P600 components in both groups were significantly higher when identifying real words compared to when identifying pseudo-words [$F(1, 34) = 14.33$, $p < 0.01$, $\eta_p^2=0.37$]. In the dyslexia group, the latency of the P600 was significantly longer in both word types than the control group [$F(1, 34) = 18.32$, $p < 0.001$, $\eta_p^2=0.41$]. Additionally, the latencies in both groups were significantly delayed when identifying pseudo-words compared to when identifying real words [$F(1, 34) = 16.31$, $p < 0.001$, $\eta_p^2=0.39$].

Discussion

The current study investigated the time course of brain activity during the processing of words and pseudo-words in Chinese developmental dyslexics and age-matched controls. The lexical decision task we used is indicative of orthographic-semantic processing (words) and phonological processing (pseudo-words), both of which are basic cognitive skills needed for the reading. The lexical decision task has been known to distinguish between regular and dyslexic readers (Perfetti, 1994; Shaul, Arzouan, & Goldstein, 2012). In terms of behavioral data, the dyslexics were significantly slower and less accurate than the controls. The behavioral measures also indicated better performance in the word compared to the pseudo-word condition, especially in the dyslexic group, and this result is consistent with previous studies (Vellutino, 1979; Nicolson & Fawcett, 1994, 1995; Mechelli *et al.*, 2003; Taroyan & Nicolson, 2009; Shaul, Arzouan, & Goldstein, 2012). This difference may be due to the greater processing demands needed for unfamiliar or meaningless pseudowords

compared to familiar and frequently used words. therefore recognizing pseudo-words required longer RTs (Kronbichler, 2004). Although the amplitude of N400 component in the dyslexia group was found significantly higher than the control group in the current study, the controls group, on the whole, exhibited greater brain activity than dyslexics during the lexical decision task. This is consistent with previous findings showing that less brain activity in dyslexics compared to fluent readers during reading tasks (Helenius *et al.*, 1999a, b; Salmelin & Helenius, 2004; Paulesu *et al.*, 2001; Shaywitz *et al.*, 2006). In this study, although Chinese characters differ their letters from other languages, we observed the similar results. The results suggest that dyslexics at different ages who speak different languages may exhibit similar defects (Taroyan & Nicolson, 2009; Shaul, Arzouan & Goldstein, 2012).

The N130 is a negative, early semantic processing stage component with a latency of 100–150 ms. Its amplitude is affected by various text attributes such as orthography factors, word recognition, semantic accessibility, and overall cognition. The present study found that the N130 component appeared about 130 ms after the onset of the presented word stimuli (also referred to as N130). Although the amplitude of N130s did not differ between the dyslexia group and control group, the latency was significantly delayed in the dyslexia group compared to the control group in the pseudo-word judgment condition. These results suggest the existence of early word recognition defects in dyslexic children. Similar word/pseudo-word differences in early brain activation also have been found in other ERP studies (Serenio *et al.*, 1998; Hauk *et al.*, 2006; Taroyan & Nicolson, 2009; Dujardin *et al.*, 2011; Shaul, Arzouan, & Goldstein, 2012).

Recognition potential (RP) is an electrical brain response peaking approximately 250 ms when subjects view recognizable images, such as words or pictures (Rudell, A. P., 1991). In the word condition, a significant positive component occurred around 230 ms after stimulus presentation (RP) and it seems to index the processing of word meaning (Iglesias, A. 2004). Rudell *et al.* (1990, 2000) found that the recognition of language form induces a positive wave known as the RP component that peaks in the range of 200~250 ms, which is also believed to be related to word composition and shape recognition. Luo *et al.* (2008) stated that the RP component may reflect an early type of visual

information processing. This early visual category information processing is a rough classification, which enables people to quickly distinguish different types of stimuli and reduces the cognitive load. Combined with the above view, we infer that the observed differences in RP amplitude between the control and dyslexia groups may reflect early defects in the capacity of category sorting and processing among children with dyslexia.

The N400 component has previously been shown to reflect sentence processing and semantic integration. In this study, using Chinese double words, we also found significant N400 effects. Although this component also has other uses in adults (Taroyan & Nicolson, 2009; Shaul, Arzouan, & Goldstein, 2012), the current study focusing on children (mean 12.8 years) showed that it is very important in the advanced stages of processing. What is more, the amplitude of the N400 component during both the word and pseudo-word conditions in the dyslexia group was significantly higher, while the N400 latency in the dyslexia group was significantly delayed. The results also showed that in the pseudo-word recognition, the amplitude of the N400 component in dyslexic children was significantly higher. Consistent with previous findings (Nobres, & Holcomb, 1995; Hauk *et al.*, 2006; Dujardin *et al.*, 2011), these results suggest that pseudo-word recognition under conditions of semantic processing took more time for participants in the dyslexia group than for participants in the control group, which indicate that children with dyslexia may need to devote more cognitive resources when recognizing words, thus implying there is a semantic integration defect in dyslexic children. Although the material used in current study is different from the former studies adopting the ambiguous sentence as stimuli, the finding that we also observed the similar N400 effects in our study might also convince us that Children with dyslexic exhibit defect not only at the level of sentence meaning processing but also semantic world processing.

Chinese word recognition is similar to the word recognition in other phonetic languages. The present study found that when presented with the same recognition task, both normal and dyslexic Chinese children showed P600 effects. We also found that in the dyslexia group, the pseudo-word condition was associated with a longer latency and lower amplitude compared to the control group. It is generally believed that the P600 component reflects the later stages of semantic

integration and decision processes. This may be due to post-processing difficulties and flawed semantic integration in these children during reading, with fewer resources being available for a longer duration. The dyslexic group was impaired in the later cognitive stages of lexical decision-making and response-choice processes. The increased activation during the pseudo-word condition may be also associated with the notion that greater processing demands are required for pseudo-words compared to frequently used words (Kronbichler *et al.*, 2004). These results suggest that when performing the same tasks, the dyslexic children need more cognitive resources and processing time than the control group.

It should be noted that the present study explored the temporal rather than spatial characteristics of neural responses in a lexical decision task." Future research should use multi-lead source analysis in order to establish which brain regions are involved. Meanwhile, that the current study recruited 13-year-old dyslexic children as participants may also limit the interpretation of these results since age is an important factor that can affect the ERP waveform. The semantic processing of Chinese dyslexic children in different ages should be tested further in the future. We should also be cautious that it is not clear whether the delays seen in the early and later ERP components are specific to language stimuli, which deserves to be considered in the further study.

Conclusion

Chinese dyslexic children exhibited typical semantic processing defects during a word recognition task. The time course of semantic processing in the Chinese dyslexic children showed that the defects first manifested in the N130 and RP components and occurred prior to 250 ms, reflecting early defects in morpheme integration and category sorting capacity in Chinese dyslexics. The presentation of word stimuli evoked the typical N400 effect, showing that dyslexic children had difficulties with semantic integration during the medium stages of processing. There were also differences between the two groups at later processing stages (600 ms), reflecting difficulties in decision-making in children with dyslexia. As ideographic characters and phonetic system similarities, there are semantic processing defects in Chinese dyslexic children.

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References

- Bonte ML, Poelmans H, Blomert L. Deviant neurophysiological responses to phonological regularities in speech in dyslexic children. *Neuropsychologia* 2007; 45(7): 1427-37.
- Breznitz Z. Speed of phonological and orthographic processing as factors in dyslexia: Electrophysiological evidence. *Genetic, Social, and General Psychology Monographs* 2003; 129(2): 183-206.
- Csepe V, Szücs D, Honbolygó F. Number-word reading as challenging task in dyslexia? An ERP study. *International Journal of Psychophysiology* 2003; 51(1): 69-83.
- David WC, Rourke BP. Learning-disabled brains: A review of the literature. *Journal of Clinical and Experimental Neuropsychology* 2003; 25(7):1011-34.
- Dujardin T, Etienne Y, Contentin C, Bernard C, Largy P, Mellier D, Lalonde R, Rebaï M. Behavioral performances in participants with phonological dyslexia and different patterns on the N170 component. *Brain and Cognition* 2011; 75(2): 91-100.
- Helenius P, Uutela K, Hari R. Auditory stream segregation in dyslexic adults. *Brain* 1999; 122(5): 907-13.
- Ho CS, Chan DW, Chung KK, Lee SH, Tsang SM. In search of subtypes of Chinese developmental dyslexia. *Journal of Experimental Child Psychology* 2007; 97(1): 61-83.
- Hoeks JC, Stowe LA, Doedens G. Seeing words in context: the interaction of lexical and sentence level information during reading. *Cognitive Brain Research* 2004; 19(1): 59-73.
- Ho CS, Chan DW, Lee SH, Tsang SM, Luan VH. Cognitive profiling and preliminary subtyping in Chinese developmental dyslexia. *Cognition* 2004; 91(1): 43-75.
- Ho CS, Chan DW, Chung KK, Lee SH, Tsang SM. In search of subtypes of Chinese developmental dyslexia. *Journal of Experimental Child Psychology* 2007; 97(1): 61-83.
- International Classification of Diseases (ICD 10), WHO. (2009). Available at: <http://www.who.int/classifications/icd/en/>. Accessed August, 18.
- Iglesias A, Martín-Loeches M, Hinojosa JA, Casado P, Muñoz F, Fernandez-Frias C. The recognition potential during sentence presentation: stimulus probability, background stimuli, and SOA. *International Journal of Psychophysiology* 2004; 52(2): 169-86.
- Kim A, Sikos L. Conflict and surrender during sentence processing: An ERP study of syntax-semantics interaction. *Brain and Language* 2011; 118(1): 15-22.
- Kolk HH, Chwilla DJ, Van Herten M, Oor PJ. Structure and limited capacity in verbal working memory: A study with event-related potentials. *Brain and Language* 2003; 85(1): 1-36.
- Kronbichler M, Hutzler F, Wimmer H, Mair A, Staffen W, Ladurner G. The visual word form area and the frequency with which words are encountered: evidence from a parametric fMRI study. *Neuroimage* 2004; 21(3): 946-53.
- Kuperberg GR. Neural mechanisms of language comprehension: Challenges to syntax. *Brain Research* 2007; 1146: 23-49.
- Kuperberg GR, Sitnikova T, Caplan D, Holcomb PJ. Electrophysiological distinctions in processing conceptual relationships within simple sentences. *Cognitive Brain Research* 2003; 17(1): 117-29.
- Kutas M, Federmeier KD. Thirty years and counting: finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology* 2011; 62: 621-47.
- Kutas M, Hillyard SA. Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science* 1980; 207(4427):203-5.
- Laasonen M, Service E, Virsu V. Crossmodal temporal order and processing acuity in developmentally dyslexic young adults. *Brain and Language* 2002; 80(3): 340-54.
- Luo JL, Qiu J, Huai ZC, Zhang QL (2008). Sentence processing level in the brain mechanisms of judgment task. *Journal of Southwest University (Natural Science Edition)*, 2008; 30(6): 168-73.
- Lyon GR, Shaywitz SE, Shaywitz BA. A definition of dyslexia. *Annals of Dyslexia* 2003; 53(1):1-14.
- Lv C, Wang Q. Font effects of Chinese characters and pseudo-characters on the N400: Evidence for an orthographic processing view. *Brain and Cognition* 2012; 80(1): 96-103.
- Maganioti AE, Hountala CD, Papageorgiou CC, Kyprianou MA, Rabavilas AD, Capsalis CN. Principal component analysis of the P600 waveform: RF and gender effects. *Neuroscience Letters* 2010; 478(1): 19-23.
- Matthews JA, Wnek GE, Simpson DG, Bowlin GL. Electrospinning of collagen nanofibers. *Biomacromolecules* 2002; 3(2): 232-8.
- Max C, Curtis B, Atkins P, Haller M. Models of reading aloud: Dual-route and parallel-distributed-processing approaches *Psychological Review*; 100(4): 589-608.
- Mechelli A, Gorno-Tempini ML, Price CJ. Neuroimaging studies of word and pseudoword reading: consistencies, inconsistencies, and limitations. *Journal of Cognitive Neuroscience* 2003; 15(2): 260-71.
- Meyler A, Breznitz Z. Visual, auditory and cross-modal processing of linguistic and nonlinguistic temporal patterns among adult dyslexic readers. *Dyslexia* 2005; 11(2): 93-115.
- Nicolson RI, Fawcett AJ, Dean P. Developmental dyslexia: the cerebellar deficit hypothesis. *Trends in Neurosciences* 2001; 24(9): 508-11.
- Nobre AC, Mccarthy G. Language-related field potentials in the anterior-medial temporal lobe: II. Effects of word type and semantic priming. *Journal of Neuroscience* 1995; 15(2): 1090-8.
- Osterhout L, Holcomb PJ. Event-related brain potentials elicited by syntactic anomaly. *Journal of memory and language* 1992; 31(6):785-806.
- Paulesu E, Démonet JF, Fazio F, McCrory E, Chanoine V, Brunswick N, Cappa SF, Cossu G, Habib M, Frith CD, Frith U. Dyslexia: cultural diversity and biological unity. *Science* 2001; 291(5511):2165-7.
- Perfetti, CA. Psycholinguistics and reading ability. In: Gernsbacher, M.A. (Ed.), *Handbook of Psycholinguistics*. Academic Press, San Diego, 1994, pp. 849-885.

- Price CJ, Wise RJ, Frackowiak RS. Demonstrating the implicit processing of visually presented words and pseudowords. *Cerebral Cortex* 1996; 6(1): 62-70.
- Rudell AP. The recognition potential : a visual response evoked by recognizable images. *Neuroscience Abstracts* 1990; 16: 106.
- Rudell AP. The recognition potential contrasted with the P300. *International Journal of Neuroscience*. 1991; 60(1): 85-111.
- Rudell AP, Hu B. Behavioral and brain wave evidence for automatic processing of orthographically regular letter strings. *Brain and Language* 2000; 75(2): 137-52.
- Shaywitz SE. Dyslexia. *New England Journal of Medicine* 1998; 338(5): 307-12.
- Salmelin R, Helenius P. Functional neuroanatomy of impaired reading in dyslexia. *Scientific Studies of Reading* 2004; 8(3): 257-72.
- Schacht A, Sommer W, Shmuilovich O, Martfienz PC, Martn-Loeches M. Differential task effects on N400 and P600 elicited by semantic and syntactic violations. *PloS One* 2014; 9(3): e91226. doi:10.1371/journal.pone.0091226.
- Schulte-Körne G, Bruder J. Clinical neurophysiology of visual and auditory processing in dyslexia: a review. *Clinical Neurophysiology* 2010; 121(11): 1794-809.
- Sereno SC, Rayner K, Posner MI. Establishing a time-line of word recognition: evidence from eye movements and event-related potentials. *Neuroreport* 1998; 9(10): 2195-200.
- Shaul S, Arzouan Y, Goldstein A. Brain activity while reading words and pseudo-words: A comparison between dyslexic and fluent readers. *International Journal of Psychophysiology* 2012; 84(3): 270-6.
- Shaywitz BA, Lyon GR, Shaywitz SE. The role of functional magnetic resonance imaging in understanding reading and dyslexia. *Developmental Neuropsychology* 2006; 30(1): 613-32.
- Shu H, McBride-Chang C, Wu S, Liu H. Understanding chinese developmental dyslexia: Morphological awareness as a core cognitive construct. *Journal of Educational Psychology* 2006; 98(1):122-33.
- Shu H, Meng X, Chen X, Luan H, Cao F. The subtypes of developmental dyslexia in Chinese: Evidence from three cases. *Dyslexia* 2005; 11(4): 311-29.
- Simos PG, Breier JI, Fletcher JM, Foorman BR, Mouzaki A, Papanicolaou AC. Age-related changes in regional brain activation during phonological decoding and printed word recognition. *Developmental Neuropsychology* 2001; 19(2): 191-210.
- Snowling, M.J. (2000). *Dyslexia*. 2nd Edn. Oxford: Blackwell.
- Spiromelli C, Angrilli A. Developmental aspects of automatic word processing: language lateralization of early ERP components in children, young adults and middle-aged subjects. *Biological Psychology* 2009; 80(1): 35-45.
- Stevenson HW, Stigler JW, Lucker GW, Lee SY, Hsu CC, Kitamura S. Reading disabilities: the case of Chinese, Japanese, and English. *Child Development*. 1982; 53(5): 1164-81.
- Shu H, Bai XL, Han ZZ & Bi YC. Lexical Representation and Processing Theory and evidence of cognitive neuropsychology. *Chinese Journal of Applied Psychology* 2003; 9(2): 41- 45.
- Shu H, Anderson RC. Role of radical awareness in the character and word acquisition of Chinese children. *Reading Research Quarterly* 1997; 32(1): 78-89.
- Shu H, Meng XZ. Chinese children's reading difficulties Exploration - statistics from dyslexia children. *Applied Linguistics* 2000; 3: 63-69.
- Shu H, McBride-Chang C, Wu S, Liu H. Understanding chinese developmental dyslexia: Morphological awareness as a core cognitive construct. *Journal of Educational Psychology*. 2006; 98(1): 122.
- Taroyan NA, Nicolson RI. Reading words and pseudowords in dyslexia: ERP and behavioural tests in English-speaking adolescents. *International Journal of Psychophysiology* 2009; 74(3):199-208.
- Wang E, Qin S, Chang M, Zhu X. Digital memory encoding in Chinese dyscalculia: An event-related potential study. *Research in Developmental Disabilities* 2015; 36: 142-9.
- Wang E, Du C, Ma Y. Old/New Effect of Digital Memory Retrieval in Chinese Dyscalculia: Evidence from ERP. *Journal of learning disabilities* 2015; 50(2): 158-67.
- Wang JJ, Bi HY, Gao LQ, Wydell TN. The visual magnocellular pathway in Chinese-speaking children with developmental dyslexia. *Neuropsychologia*. 2010; 48(12): 3627-33.
- Weekes BS, Chen MJ, Gang YW. Anomia without dyslexia in Chinese. *Neurocase* 1997; 3(1): 51-60.
- Wimmer H, Hutzler F, Wiener C. Children with dyslexia and right parietal lobe dysfunction: event-related potentials in response to words and pseudowords. *Neuroscience Letters*; 2002; 331(3): 211-13.
- Wu SG, Shu H, Liu YR. Role of children in the morphological awareness of Chinese reading. *Psychology and Behavior* 2005; 3: 35-38.
- Zhou X, Meng X, Chen Y. Brainimaging studies of developmental dyslexia. *Chinese journal of neuroscience* 2002; 18(2): 568-72.