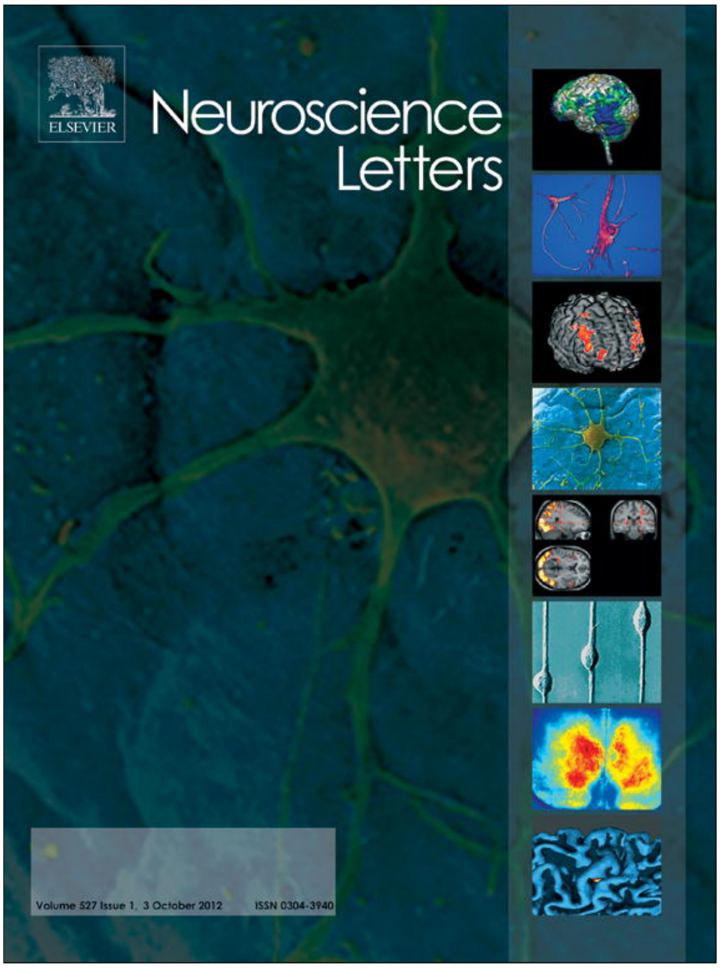
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Automatic integration of auditory and visual information is not simultaneous in Chinese

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HIGHLIGHTS

- MMN indicates unique timing mechanisms for character–tone integration in Chinese.
- Grapheme–phoneme correspondence and character–tone correspondence are not equivalent.
- The type of writing system impacts cognition and the underlying neural systems.

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ABSTRACT

ERP studies have revealed that for alphabetic languages letter/speech-sound integration develops with brain maturation and reading instruction over a relatively long period of time. Experienced adult readers associate letters and speech sounds automatically, as indexed by enhanced mismatch negativity (MMN) to simultaneously presented stimuli, but reveal attenuated MMN when the speech sound stimuli are presented with a delay. Chinese as a logographic language differs substantially from alphabetic languages and therefore integration processes might be characterized by unique timing mechanisms. In the present study, MMN was used to investigate the timing and automaticity of association between characters and lexical tones in adult native Chinese speakers. A character was presented simultaneously with a lexical tone, or with either a 100 ms stimulus onset asynchrony (SOA) or a 200 ms SOA in separate conditions. MMN was enhanced when the character and the lexical tone were presented with 100 ms SOA, while no significant MMN enhancement was observed with simultaneous presentation or with 200 ms SOA. These results suggest that the automatic association of characters and lexical tones in experienced Chinese adult readers requires more processing time than for alphabetic languages. These results highlight critical differences between fundamental reading processes across different writing systems. The neural differences between alphabetic and logographic languages for letter/character and speech-sound/tone integration need to be taken into consideration when considering past and future research on reading processes in these languages and especially for investigations of reading disorders, such as developmental dyslexia.

1. Introduction

In alphabetic languages learning to read is a multistage process that presupposes the establishment of associations between letters and speech sounds. There are many models describing the process of learning to read that emphasize the generation of these associations (grapheme–phoneme correspondence) as a crucial first step in alphabetic languages [4]. A main difference of logographic languages, such as Chinese, is that grapheme–phoneme correspondences are not used for character pronunciation [14]. Instead, Chinese characters map onto syllables at a monosyllabic level, meaning that visual aspects of the character do not map onto phonemes of a character's pronunciation.

The neural correlates of how characters and lexical tones map onto one another has not yet been explored. However, a series of cross-modal investigations examined the time course and automaticity of letter/speech-sound integration in healthy, normally reading adults. Standard and deviant letter/speech sound pairs were presented in an audiovisual (AV) oddball experiment with differing stimulus onset asynchronies (SOA) [3]. Mismatch negativity (MMN) elicited by the visual presentation of letters and the auditory presentation of congruent and incongruent speech-sounds was investigated. The visual stimulus was the letter "a", while

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the standard speech sound was /a/ and the deviant speech sound was /o/. (A speech sound only condition (A_only) was employed as a control condition.) Speech sounds were presented with either no delay (0 ms, AV_0), a 100 ms delay (AV_100) or a 200 ms delay (AV_200). MMN in AV_0 was significantly larger over fronto-central sites than MMN in the A_only condition, but not for AV_100 or AV_200, suggesting early and automatic processing of letters and speech-sounds.

Subsequent investigations on early readers showed delayed letter/speech-sound association related to MMN activity around 650 ms [2]. Only after 4 years of reading instruction did children's MMN begin to resemble that of experienced adult readers, however the association required an extra 100 ms (MMN enhanced in AV_100). These findings strongly suggest that letter/speech-sound integration develops with brain maturation and reading instruction over a relatively long period of time.

Understanding how letters and sounds are integrated in alphabetic languages is not only important for understanding the neurobiology behind fluent reading, but also for aiding in understanding the processes in disabled reading. It is accepted that failure to develop these representations during reading acquisition might contribute to reading problems such as those found in developmental dyslexia (DD) [22]. It could also be shown that children with dyslexia who had received 4 years of reading instruction revealed no signs of automatic letter/speech-sound integration, despite accurate letter knowledge. Instead MMN was comparable to beginner readers with only 1 year of reading instruction [6].

Arguably, it is critical to also gain insight into the neural correlates behind the integration of visual and auditory language units in other writing systems, such as a tonal language like Chinese [33]. A number of studies examining advanced language processing, e.g. orthographic, phonological and semantic integration, in Chinese indicate the involvement of different neural networks than those described for analogous processing in alphabetic writing systems [7,20,21,25,28,26,27]. Thus, reading processes and their neural correlates likely accommodate to specific visual and structural features attributed to the writing system [13], making it necessary to understand language processing as a function of writing system. To date, a research bias exists for the English language.

According to Pike [15] a tonal language has three important features. First, tones are lexically significant in that they distinguish the meaning of words. Second, tones are contrastive in that listeners extract physical dimensions that permit the categorisation of lexically significant tones into functional categories. Third, relative pitch height accounts for lexical identity, not actual pitch. In Mandarin, single syllabic character pronunciation is commonly defined by a consonant, a vowel and a lexical tone. Four major tones characterize Mandarin. With the exception of the first, flat tone, these have slow frequency changes over time (spectrally variant) [8]. Tone has some resemblance to intonation in English, although intonation rarely carries lexical information. In Chinese, there are nearly 338 syllables for approximately 100,000 characters. Therefore, many characters may share one syllable [32], where tones allow for specification of unique lexical items (e.g. the syllable /ma/: tones 1–4 mean *mother*, *linen*, *horse*, *swear*) [32]. Therefore, because minor tone variations imply different meanings across Chinese syllables, tone perception is essential to detect and decode Chinese words. Finally, detecting tone differences also likely aids in distinguishing characters and increases confidence in mapping characters onto speech segments [9].

MMN [12] investigations have opened an unprecedented window to understand central auditory processing and the underlying neurophysiology of sound perception, and has also been employed in investigations of Chinese lexical tone perception [8,10].

In this present study, we used MMN to explore timing mechanisms of character/lexical tone integration in native Chinese speakers. To achieve our goal we modified the paradigm used by Froyen et al. [3,2,6] for the Chinese language. We hypothesized that the integration process of Chinese character/lexical tone pairs should also be automatic and early in normally developed Chinese adults, however because alphabetic and tonal languages are dramatically different, with Chinese being more complex, we could not assume that this integration would also be simultaneous. Therefore, the present study's foremost aim is to establish knowledge regarding character/tone integration in healthy Chinese adults and compare these results to previous findings with adults speaking alphabetic languages.

2. Method

2.1. Subjects

Twelve native Mandarin speaking postgraduate students (mean age 26.50 ± 1.73 years, right-handed, musically untrained, 5 males) without any history of hearing or reading problems and with corrected or normal vision participated in this study. Participants gave informed written consent and received a €20 gift certificate. Experimental procedures were approved by the Ethical Committee of the Faculty of Medicine at the University of Munich, Germany.

2.2. Stimuli and procedure

In an oddball paradigm Chinese lexical tones were presented in four conditions. We compared MMN evoked by deviant speech-sounds (A_only condition) with MMN evoked by the same deviant speech-sounds combined with a visually presented character (AV conditions). Stimuli were natural Mandarin speech-sounds, /yi1/ and /yi3/, and the visually presented character was "以 /yi3/". /yi3/ has a high frequency (2186.878/10,000) and many ambiguous meanings akin to prepositions in English, i.e. "to", "of", thus it contains no semantic information and should not induce a lexical process much like speech sounds [16]. Chinese characters have between 1 and 25 strokes, and character complexity increases with stroke count [23]. Eight strokes is average, thus "以 " (4 strokes) is a relatively simple character [11]. Speech sounds were digitally recorded from a native female Mandarin speaker. Recordings were band-pass filtered (180–10.000 Hz) and resampled at 22.05 kHz and matched for loudness. The sounds were presented binaurally via Sennheiser PX200 headphones at about 65 dB SPL. The character was presented for 500 ms ("bold", size 48, white on black background, centered). A black screen (150 ms), a white fixation cross (300 ms), and another black screen (400 ms) followed. Stimuli were presented pseudo-randomly to ensure at least two standard stimuli occurred between each deviant stimulus. No more than 9 standard stimuli occurred before a deviant stimulus. Subjects sat 90 cm away from the screen (visual angles: horizontal 1.91°, vertical 2.23°).

The four conditions (A_only, AV_0, AV_100, and AV_200) were presented in separate blocks of 500 trials and were presented in a pseudorandom order to participants. Forty distraction trials (1350 ms) were randomly interspersed in the AV conditions to ensure subject focus and to distract attention. Subjects viewed famous scenic pictures (e.g. the Great wall, the pyramids) and judged whether the photos were taken in China. The first 10 trials of each block were excluded in analysis. In all conditions subjects listened passively to /yi3/ (standard, 82%) and /yi1/ (deviant, 18%). In A_only a silent movie was shown, whereas in the AV conditions watched the character "以 /yi3/". SOA between character presentation and speech-sound in the three AV conditions was manipulated: simultaneous presentation for AV_0, and a 100 and 200 ms SOA for AV_100 and AV_200.

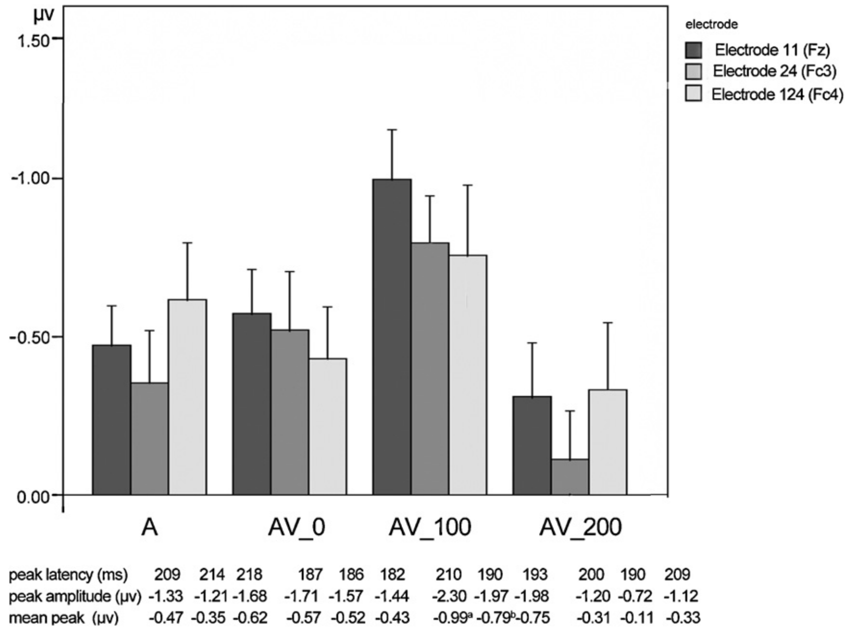

Fig. 1. Mean peak and latency amplitude values over 40 ms around the individually assessed MMN peak for the electrodes 11 (Fz), 24 (Fc3) and 124 (Fc4). The bar represents standard error. The paired *t*-test conducted on mean peak amplitude between A and AV_100 was significant for electrode 11[a] ($p = 0.01$) and electrode 24[b] ($p = 0.05$). Electrode 124 was not significant.

2.3. EEG recording

EEG was recorded continuously with an Electrical Geodesic Inc. (EGI) 128-channel-system with Cz as the reference electrode. The impedance was kept below 50 kΩ and sampled at 500 Hz. Further analysis steps were performed with Brainvision Analyzer. After EOG-artifacts removal with Independent Component Analysis, exclusion of other artifacts (gradient: max 50 μV; max–min: 150 μV for 200 ms; amplitude: min −150 μV; max 150 μV; low activity: 0.50 μV for 100 ms), and filtering (bandpass 0.3–30 Hz), EEG was referenced to the average reference. ERPs were calculated by averaging epochs of 650 ms (including a prestimulus baseline of 50 ms) separately for standard and deviant stimuli. Only standard stimuli presented before deviant stimuli were included. MMN was derived from subtracting standard and deviant stimuli.

2.4. Data analysis

Based on typical MMN studies we analyzed electrodes 11(Fz), 24(Fc3) and 124(Fc4). Due to visual data inspection and the typically reported MMN window (100–200 ms) [18,19] we extracted individual peak latencies between 50 and 300 ms after auditory stimulus onset. Mean amplitude (taken from 20 ms before and 20 ms after the peak) and individual peak latency were examined for each subject, condition and electrode.

3. Results

3.1. MMN characteristics

Fig. 1 shows peak amplitude and latency values for each electrode. To ensure significant MMN activity we first analyzed the A_only control condition, which elicited a typical fronto-central topography (Fig. 2C). A one-sample *t*-test on mean peak amplitude over each electrode revealed significant negative activity on electrodes Fz and Fc4 ($ps < .05$) and marginally significant activity over Fc3 ($p = .056$).

Next, we analyzed the AV conditions. One sample *t*-tests revealed that the mean peak amplitudes were significantly negative on each electrode in the AV_0 and AV_100 condition. In the AV_200 condition significant negative activation was found on electrode Fz ($p = .035$), but not on electrode Fc3 ($p = .48$) and electrode Fc4 ($p = .15$). The one-sample *t*-tests for peak amplitudes however revealed significant negative activation over all electrodes and conditions ($ps < .05$). For all conditions, latency was around 200 ms, which is consistent with previous ERP research using Chinese lexical tones [8].

3.2. MMN comparison: A_only vs the AV conditions

We used a 4 (*conditions*) × 3 (*electrode sites*) repeated measures ANOVA to analyze mean peak amplitude and latency. For latency, no significant main effects or interactions were found. For mean peak amplitude a significant main effect was found for *conditions* ($F(3, 9) = 7.50$, $p < 0.01$). Paired samples *t*-tests on mean peak amplitudes between A_only and the three AV conditions were run. A significant difference was found between A_only and AV_100 conditions for electrodes Fz ($t = 3.05$, $p = 0.01$) and Fc3 ($t = 2.19$, $p = 0.05$). MMN in AV_0 and AV_200 conditions did not differ from the A_only condition.

4. Discussion

According to previous research, automatic letter/speech-sound integration occurs simultaneously (AV_0) in normally reading adults [3]. Based on this finding, we explored integration of analogous language elements in Chinese, a logographic writing system.

We observed a typical MMN to deviant lexical tones. However, there was no significant MMN enhancement observed when characters and lexical tones were presented simultaneously (AV_0). Instead, the MMN was significantly enhanced when characters and lexical tones were presented with a 100 ms SOA.

Our findings suggest that the integration of visual and auditory language units in different writing systems is unique and that the automatic integration of characters and lexical tones requires an

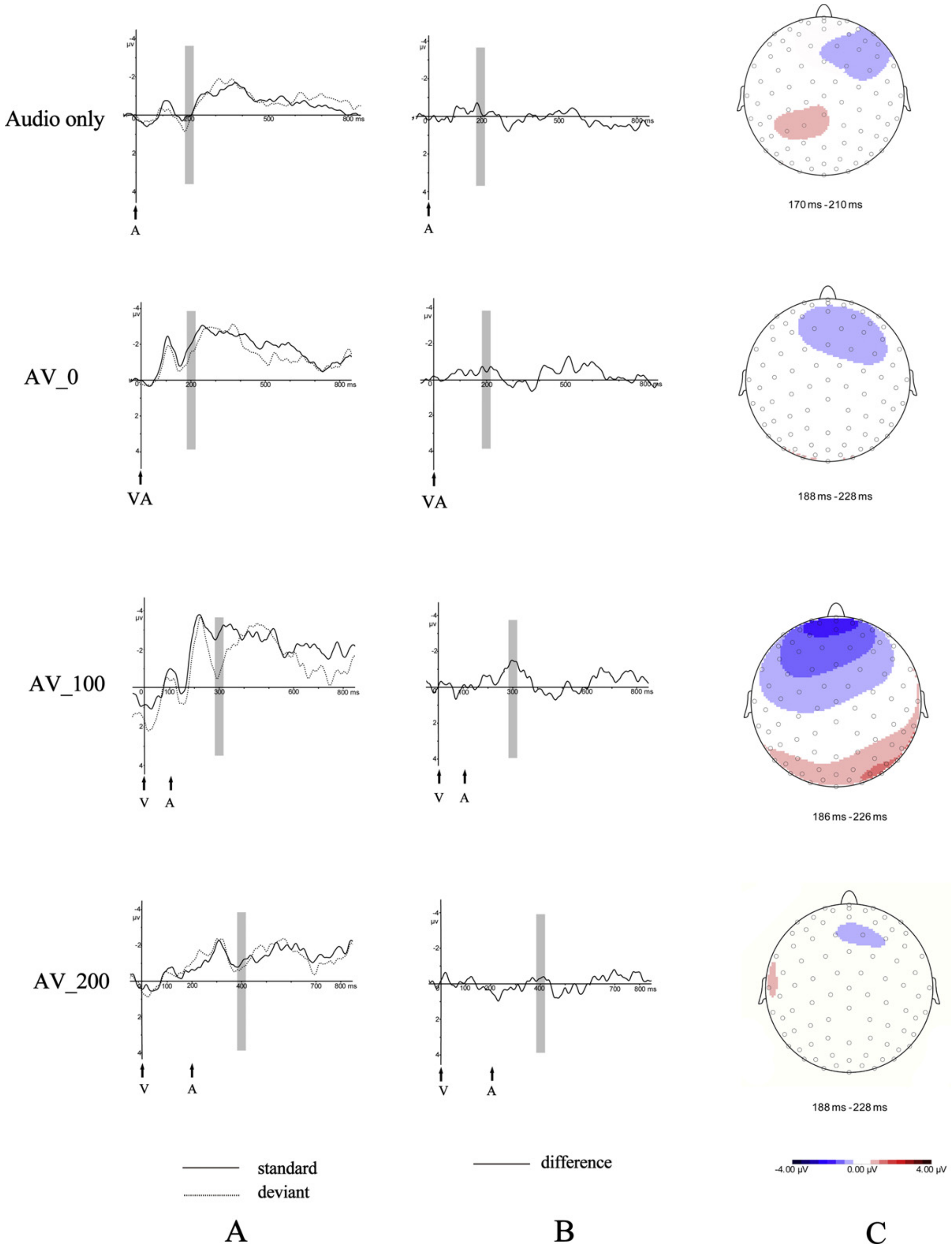

Fig. 2. Grand average ERPs for electrode 11 (Fz). (A) Standard and deviant stimuli; (B) Difference waves (MMN); and (C) MMN scalp distribution for the A_only condition and the AV_conditions. Arrows indicate the onset of visual (V) and auditory (A) stimuli. The gray area shows the MMN time-window.

extra 100 ms to form a compound stimulus. There are a number of differences between alphabetic and Chinese writing systems that might account for an increased integration time in Chinese.

Firstly, our character ("以") and the letter used in previous studies ("a") are visually very distinct, however we do not think that physical differences can account for the delayed integration in our study. We would suggest that fluent reading Chinese adults should be able to automatically recognize "以", just like fluent reading adults would recognize "a". However, it is important to note that Tan et al. [26,24] argue that Chinese requires more visual processing and analysis and additional cortical areas, compared to alphabetic languages. These authors have consistently found increased activation in additional right hemispheric areas for Chinese. Although differences between characters and letters may have contributed to our unique findings, we feel that there are better interpretations available for our data.

Probably more relevant are the differences between the writing systems themselves. Characters and letters impact the reading process differently within each writing system. All languages activate phonology at the lowest level that is possible within the constraints of the writing system [14]. Alphabetic languages rely on grapheme–phoneme correspondences for fluent reading. In particular, Dutch (language of previous research) has a rather transparent orthography [34]. In contrast, the elementary phonological unit in Chinese is a spoken syllable, which is also a morpheme, and sometimes a word [13]. Therefore, Chinese activates phonology at the syllable level, not at the sub-syllabic level as in alphabetic languages. These processes reflect fundamentally different ways of reading between Chinese and alphabetic languages. According to Perfetti and Lui [13] alphabetic writing systems activate phonology incrementally with each letter–phoneme pair, whereas Chinese characters must be recognized as an orthographic unit to activate syllable-phonology.

It is these differences between how characters and lexical tones and how letters and speech sounds map onto each other that we argue contribute most to the differences found between our study and previous studies. The enhanced MMN found in Froyen et al. [3,2,5] for simultaneous presentation might represent the mismatch of non-corresponding grapheme and phoneme units. The MMN recorded in the present experiment would therefore result from fundamentally unique processes to logographic cross-modal integration of characters and tones.

Our research further suggests that after 100 ms the automatic integration of characters and lexical tones has been completed, as there was no subsequent MMN enhancement in the AV_200 condition. Although not simultaneous, as in Dutch, the narrow time window suggests that the character/Chinese lexical tone integration should also be a rigid, inflexible and low-effort process in advanced Chinese native speakers, as it fulfills the main criteria for automatic processing in general as formulated by Schneider and Chein [17].

For alphabetic languages, some models describing the process of learning to read emphasize the generation of letter to speech-sound connections as a crucial first step in the learning process and the failure of this step in reading acquisition is considered a main cause for reading problems like in DD [1]. Failure to show enhanced MMN in cross-modal presentation in Dutch individuals with DD was reported [6]. This process has been suggested as critical for reading failure in childhood and also was found to persist into adulthood [1,29]. Likewise, the integration of Chinese characters and lexical tones should also be crucial for DD in the Chinese language and deserves careful consideration in future research.

Finally, we would like to mention that the MMN amplitude in our research was relatively low (around $-1.0\,\mu v$), which is lower than some MMN recorded using speech sounds, but consistent with the previous research using Chinese lexical tones [8,30,31]. Meng et al. [10] found that MMN evoked by lexical tones was lower than MMN evoked by speech sounds and syllables in the same subjects. This research suggests that lexical tones might generally elicit smaller MMN than speech sounds, however this notion has not been addressed in previous work. A simple explanation might be due to less acoustic (i.e. physical) difference between the lexical tones used in the experiments in comparison to the speech sounds, however as exact stimuli descriptions are not given, it is not possible to compare stimuli differences across studies. Additionally, it might be important to understand that lexical tones are generally distinguished based on temporal properties of the stimulus [8] whereas vowels are differentiated based on spectral differences. How these aspects might affect the MMN of Chinese lexical tones is beyond the scope of the present paper but might be an important line of investigation for further quantifying the neural response to Chinese lexical tones.

5. Conclusion

The present study is the first to investigate the automatic integration of Chinese characters and lexical tones. Considering the dramatic difference between writing systems, we compared our findings to previous investigations in the alphabetic writing system. In contrast, we found that Chinese native speakers required an extra 100 ms for the automatic integration of characters and lexical tones. We attributed this timing difference to the fundamental heterogeneity in the two writing systems, the overall increased complexity of Chinese and findings that suggest distinct neural mechanisms for the Chinese language compared to English. This study offers insight into character/lexical tone integration, which is only one important characteristic of the Chinese language. In fact, the syllable of a Chinese character consists of an initial consonant, a vowel, sometimes a final consonant, and the tone, which are all equally critical in Chinese pronunciation. Further research is needed to understand how all of the phonological components of a character are integrated. Furthermore, our study used very simple characters, but in Chinese, the complexity, frequency and meanings between characters are so varied that different degrees of automatization might be found when these elements are systematically examined.

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References

[1] L. Blomert, The neural signature of orthographic–phonological binding in successful and failing reading development, Neuroimage 57 (2011) 695–703.
[2] D.J. Froyen, M.L. Bonte, N. van Atteveldt, L. Blomert, The long road to automation: neurocognitive development of letter–speech sound processing, Journal of Cognitive Neuroscience 21 (2009) 567–580.
[3] D. Froyen, N. Van Atteveldt, M. Bonte, L. Blomert, Cross-modal enhancement of the MMN to speech-sounds indicates early and automatic integration of letters and speech-sounds, Neuroscience Letters 430 (2008) 23–28.
[4] L.C. Ehri, Development of sight word reading: phases and findings, in: M.J. Snowling, C. Hulme (Eds.), The Science of Reading: A Handbook, Blackwell Publishing, Oxford, 2005, pp. 135–154.
[5] D. Froyen, Developmental Electrophysiological Studies of Letter: Speech Sound Processing in Normal Reading and Dyslexia, Universitaire Pers Maastricht, 2009.
[6] D. Froyen, G. Willems, L. Blomert, Evidence for a specific cross-modal association deficit in dyslexia: an electrophysiological study of letter–speech sound processing, Developmental Science 14 (2011) 635–648.
[7] L. Liu, X. Deng, D. Peng, F. Cao, G. Ding, Z. Jin, Y. Zeng, K. Li, L. Zhu, N. Fan, Modality-and task-specific brain regions involved in Chinese lexical processing, Journal of Cognitive Neuroscience 21 (2009) 1473–1487.
[8] H. Luo, J.T. Ni, Z.H. Li, X.O. Li, D.R. Zhang, F.G. Zeng, L. Chen, Opposite patterns of hemisphere dominance for early auditory processing of lexical tones and consonants, Proceedings of the National Academy of Sciences 103 (2006) 6.
[9] C. McBride-Chang, F. Lam, C. Lam, S. Doo, S.W.L. Wong, Y.Y.Y. Chow, Word recognition and cognitive profiles of Chinese pre-school children at risk for dyslexia through language delay or familial history of dyslexia, Journal of Child Psychology and Psychiatry 49 (2008) 211–218.
[10] X. Meng, X. Sai, C. Wang, J. Wang, S. Sha, X. Zhou, Auditory and speech processing and reading development in chinese school children: behavioural and ERP evidence, Dyslexia 11 (2005) 19.
[11] Modern Chinese Frequency Dictionary, Beijing Language Institute, Beijing, China, 1986.
[12] R. Näätänen, Orienting and evoked potentials, in: H.D. Kimmel, E.H. van Olst, J.F. Orlebeke (Eds.), The Orienting Reflex in Humans, Erlbaum, New Jersey, 1979, pp. 61–75.
[13] C.A. Perfetti, Y. Liu, Orthography to phonology and meaning: comparisons across and within writing systems, Reading and Writing 18 (2005) 193–210.
[14] C.A. Perfetti, S. Zhang, I. Berent, Reading in English and Chinese: evidence for a universal phonological principle, Advances in Psychology 94 (1992) 227–248.
[15] K.L. Pike, Tone Languages, University of Michigan Press, Ann Arbor, MI, 1948.

[16] G. Rui, Semantic structure and semantic analysis of Chinese form words, Chinese Teaching in the World (2008) 5–15.
[17] W. Schneider, J.M. Chein, Controlled and automatic processing: behavior, theory and biological mechanisms, Cognitive Science 27 (2003) 525–559.
[18] E. Schröger, Measurement and interpretation of the mismatch negativity, Behavior Research Methods, Instruments, and Computers 30 (1998) 131–145.
[19] G. Schulte-Koerne, J. Bruder, Clinical neurophysiology of visual and auditory processing in dyslexia: a review, Clinical Neurophysiology 121 (2010) 1794–1809.
[20] W.T. Siok, Z. Jin, P. Fletcher, L.H. Tan, Distinct brain regions associated with syllable and phoneme, Human Brain Mapping 18 (2003) 201–207.
[21] W.T. Siok, C.A. Perfetti, Z. Jin, L.H. Tan, Biological abnormality of impaired reading is constrained by culture, Nature 431 (2004) 71–76.
[22] M.J. Snowling, The development of grapheme–phoneme correspondence in normal and dyslexic readers, Journal of Experimental Child Psychology 29 (1980) 294–305.
[23] M. Taft, X. Zhu, Submorphemic processing in reading Chinese, Journal of Experimental Psychology: Learning, Memory, and Cognition 23 (1997) 761.
[24] L.H. Tan, J.A. Spinks, J.H. Gao, H.L. Liu, C.A. Perfetti, J. Xiong, K.A. Stofer, Y. Pu, Y. Liu, P.T. Fox, Brain activation in the processing of Chinese characters and words: a functional MRI study, Human Brain Mapping 10 (2000) 16–27.
[25] L.H. Tan, C.M. Feng, P.T. Fox, J.H. Gao, An fMRI study with written Chinese, NeuroReport 12 (2001) 83.
[26] L.H. Tan, H.L. Liu, C.A. Perfetti, J.A. Spinks, P.T. Fox, J.H. Gao, The neural system underlying Chinese logograph reading, Neuroimage 13 (2001) 836–846.
[27] L.H. Tan, J.A. Spinks, C.M. Feng, W.T. Siok, C.A. Perfetti, J. Xiong, P.T. Fox, J.H. Gao, Neural systems of second language reading are shaped by native language, Human Brain Mapping 18 (2003) 158–166.
[28] L.H. Tan, A.R. Laird, K. Li, P.T. Fox, Neuroanatomical correlates of phonological processing of Chinese characters and alphabetic words: a meta-analysis, Human Brain Mapping 25 (2005) 83–91.
[29] N. van Atteveldt, E. Formisano, R. Goebel, L. Blomert, Integration of letters and speech-sounds in the human brain, Neuron 43 (2004) 271–282.
[30] X.D. Wang, F. Gu, K. He, L.H. Chen, L. Chen, Preattentive extraction of abstract auditory rules in speech sound stream: a mismatch negativity study using lexical tones, PLoS ONE 7 (2012) e30027.
[31] J. Xi, L. Zhang, H. Shu, Y. Zhang, P. Li, Categorical perception of lexical tones in Chinese revealed by mismatch negativity, Neuroscience 170 (2010) 223–231.
[32] Y. Xu, The activation of phonology during silent Chinese word reading, Journal of Experiment Psychology 25 (1999) 20.
[33] C.M.C. Yun Ye, Processing spoken Chinese: the role of tone information, Language and Cognitive Processes 14 (1999) 22.
[34] J.C. Ziegler, D. Bertrand, D. Tóth, V. Csépe, A. Reis, L. Faísca, N. Saine, H. Lyytinen, A. Vaessen, L. Blomert, Orthographic depth and its impact on universal predictors of reading, Psychological Science 21 (2010) 551.