Music Reading Expertise Modulates Hemispheric Lateralization in English Word Processing but not in Chinese Character Processing

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Abstract

Recent research has shown that expertise in English and music reading both rely more on left hemisphere (LH) processing whereas Chinese character processing is more bilateral. Accordingly, music-reading expertise may influence hemispheric lateralization in English word processing more than in Chinese processing due to stronger competition in LH processing. Here we recruited musicians and non-musicians in a divided visual field study of English word and Chinese character naming. In English word processing, whereas non-musicians showed a typical right visual field (RVF)/LH advantage, musicians showed a left visual field (LVF)/right hemisphere (RH) advantage and responded significantly faster than non-musicians in both the LVF and the center position. This effect may be due to competition for LH processing between music and English reading expertise, making musicians' English word processing more right-lateralized. In contrast, in Chinese character naming, both musicians and non-musicians showed a similar bilateral pattern. This result suggests that music reading experience may have differential influences on the processing of different languages, depending on their similarities in the cognitive processes involved.

Keywords: Music reading expertise; English reading; Chinese reading; lateralization; visual word processing

Introduction

Recent research has shown that different perceptual expertise domains may influence each other. For example, Gauthier et al. (2003) showed that car perception interfered with concurrent face perception in car experts, but not in car novices, suggesting that car and face expertise share common neural mechanisms. Similarly, formal music training has been reported to enhance musicians' nonmusical cognitive abilities (Schellenberg, 2005) and hemispheric interconnectivity (Ono et al., 2011). For example, in a line bisection task, musicians were shown to have a bilateral representation of visuo-spatial attention, while non-musicians tended to be more right-lateralized (Patston et al., 2006).

Consistent with these findings, a recent neuropsychological review revealed that 11 out of 16 representative cases of music reading deficiency due to brain lesion in the LH showed music reading difficulties accompanied by word reading difficulties (in alphabetic languages; Hebert & Cuddy, 2006), suggesting that music and alphabetical language reading may share common neural mechanisms. Indeed, recent studies have suggested that cognitive processes involved in music reading expertise tend to be left- lateralized (Segalowitz, Bebout & Lederman, 1979). LH processing has shown to be analytic (Bradshaw & Nettleton, 1981), which facilitates decoding of music notations into motor responses with auditory feedback. This decoding process is similar to the grapheme–phoneme correspondence in alphabetic languages (e.g. English). This idea has been further confirmed by visual half-field experiments: Musicians showed an RVF/LH advantage in chord reading and an LVF/RH advantage for random dot pattern recognition (Salis, 1980; Segalowitz et al., 1979). Also, similar to English word reading, the left-to-right reading direction of music notations may also contribute to a better reading performance in the RVF/LH due to perceptual learning, since the readers are more likely to recognize new words/notations in the RVF (Brysbaert & Nazir, 2005). In short, music notation reading processes are shown to be more left lateralized. Thus, if different expertise domains can influence each other, music-reading expertise may influence cognitive tasks that require LH processing more, such as English word processing, as compared with other cognitive tasks that are more right-lateralized/bilateral such as Chinese character processing.

In the research on visual word recognition, a RVF/LH advantage has been consistently reported in English word processing (Brysbaert & d'Ydewalle, 1990). It has been argued to be due to the requirement of decomposing words into letters/graphemes and mapping them to corresponding phonemes for pronunciation during learning to read (e.g., Hsiao & Lam, 2013). In addition, due to our habitual left-to-right reading direction, English words are more likely to be recognized in the RVF, leading to an RVF/LH advantage due to perceptual learning (Brysbaert & Nazir, 2005).

In contrast to English word processing, Chinese character processing tends to be more right-lateralized (Tzeng et al., 1979) or bilateral (Tan et al., 2001) due to its unique logographic orthography. Each Chinese character is regarded as a morpheme and corresponds to a syllable in the pronunciation, and components of a character do not correspond to phonemes in the pronunciation. Since there is no grapheme-phoneme correspondence in Chinese, decomposition of a character into components is not required. This may account for the LVF/RH advantage in Chinese orthographic processing observed in the literature (e.g., Tzeng et al., 1979; Tan et al., 2001; Hsiao & Lam, 2013). In contrast, an RVF/LH advantage is typically found in Chinese phonological processing (Hsiao & Cheng, 2013). These results showed that Chinese character processing tends to be more bilateral, involving a LVF/RH advantage in orthographic processing and an RVF/LH advantage in phonological processing. Different from English and music reading, Chinese can be read in all directions (left to right, right to left, or vertically). Perceptual learning thus may have less influence in Chinese reading regarding lateralization effects.

Since English word and music notation reading expertise both involve LH lateralization, we hypothesize that there may be neurocomputational resource competition between them in those who have expertise in both domains, such as musicians who are also expert English readers. Consequently, as compared with non-musicians, musicians may show reduced LH lateralization in English word processing due to their music reading expertise. In contrast, since Chinese character processing is more bilateral/right-lateralized as compared with English word processing, musicians who are also expert Chinese readers are less likely to have neurocomputational resource competition with Chinese character processing. They may show similar lateralization effects to non-musicians regardless of their music reading experience. To test these hypotheses, we investigate how music reading expertise influences hemispheric lateralization effects in English word and Chinese character naming. This study will demonstrate how different expertise domains influence each other in terms of cognitive processing.

Methods

Participants

Participants were 60 Cantonese (L1)-English (L2) bilinguals from Hong Kong, whose age ranged from 18 to 29 (M = 22, SD= 2.7). They had similar college education background. They were classified as musicians (n= 30) and non-musicians (n= 30), with 15 males and 15 females in each group. Musicians were well-trained pianists, who started music training at age 3-9 (M= 5.7, SD= 1.8). All of them were piano teachers, music undergraduate/ postgraduate students, or church piano players. They had attained grade 8 piano or above in the graded music examinations of the Associated Board of The Royal Schools of Music (ABRSM), with 8-22 years experience in piano playing (M= 15.8, SD= 4) and regular music reading hours per week (M= 9, SD= 11.4). In contrast, non-musicians did not receive any music training. All participants were right-handed and had normal or corrected to normal vision and started learning English as a second language at age 3.6. Except for their music training background, musicians' and non-musicians' linguistic background, handedness, and working memory performance were closely matched, as shown in a letter–number sequencing task (WAIS-III, Wechsler, 1997; musicians: M = 12.1; non-musicians: M = 11.7, $t(58)$ = .586, *n.s.*).

Materials

The materials consisted of four types of stimuli: English words, Chinese characters (symmetric characters and SP characters, i.e., phonetic compounds with a semantic radical on the left and a phonetic radical on the right), music notations (notes, chords) and Tibetan strings.

Four- to six-letter English words (n=108) were selected from the SUBTLEX-US corpus (Brysbaert, New & Keuleers, 2012). To control for the information distribution of the word stimuli, the same number of high frequency words and low frequency words were selected within the informative beginning and informative end subsets in Bryden et al. (1990).

As for Chinese character stimuli, Hsiao and Cheng (2013) found that naming Chinese characters with different structures had different visual field asymmetry effects due to information distribution within the characters. Thus, to control for the influence from asymmetric information distribution within characters, here we used symmetric characters as the stimuli. In addition, we included another type of character that is the most dominant in the Chinese orthography, SP characters. With a phonetic radical on the right, the information distribution of a SP character for pronunciation is skewed to the right. According to Hsiao and Cheng (2013), SP character processing may have an advantage in the LVF than the RVF because the phonetic radical of an SP character is closer to the center, where the highest visual acuity can be achieved, when being presented in the LVF than the RVF. Here we included SP characters as a representative type of characters in the orthography. In total 108 symmetric characters and 108 SP characters were used; both types of character had 12.1 average number of strokes and ranged from low to high frequency. The number of strokes and character frequency were matched according to Ho's (1998) database.

For music notations, notes (n= 96; 48 pairs) and chords (n= 108; 54 pairs), ranging from B3 to C5[1], were included. All chords were common chords without accidentals (C, F, G major, D, E, A minor and B diminished chord) in the root position, first inversion and second inversion. Six types of time values were selected: semibreves (4 beats), dotted minims (3 beats), minims (2 beats), crotchets (1 beat), quavers (1/2 beats) and semiquavers (1/4 beats).

Vertical three-letter Tibetan strings (n=216; 108 pairs) and their mirror images (n=216; 108 pairs) were included. Mirror images were used to counterbalance the information between the two sides of the stimuli.

Design

Participants completed an English word naming task, a Chinese character naming task, and a music note and chord sequential matching task, and a Tibetan string sequential matching task with the divided visual field design. The task with music notations aimed to examine whether musicians and non-musicians had different lateralization effects in music notation reading when the task depended purely on visual processing of note locations without the requirement of motor planning as in the playing tasks used in previous studies (e.g., Segalowitz et al., 1979). Tibetan strings were used as a control stimulus type.

In all tasks, the design consisted of a within-subject variable: visual field (VF) location (LVF/centre/RVF) and one between-subject variable: music expertise (musicians vs.

[1] B3 to C5 ranges across two octaves from the B note below one lower ledger line to the C note with two upper ledger lines.

non-musicians). The dependent variable was the accuracy (ACC) and response time (RT) in word reading and similarity judgments. English word length, number of strokes of Chinese characters, word/character frequency, and stimuli used in same and different trials were all matched across the LVF, RVF, center-top, or center-bottom conditions in each block. The stimulus center was 2.8° of visual angle away from the center fixation in all VF location conditions. Participants' viewing distance was 57 cm.

The English words were displayed in Times New Roman font. Each English word subtended 1.5° of visual angle horizontally and 1.1° vertically. The edge of the English word was 1.5° away from the center (Figure 1). To avoid ceiling effects, the luminance of English word was adjusted to 59.95 cd/m^2. With 210 cd/m^2 background luminance, the Weber contrast of the English word stimuli was -0.715.

The Chinese characters were in Microsoft MingLiu font. Each Chinese character subtended a horizontal and vertical visual angle of 1.5° x 1.6°. The edge of Chinese character was 2° of visual angle away from the center (Figure 1). To avoid ceiling effects, the luminance of Chinese characters was adjusted to 153.5 cd/m^2, and the Weber contrast of the Chinese character stimuli was -0.269.

Each music note and chord subtended a horizontal and vertical visual angle of 1.17° x 2.30°. The edge of the image was 2.2° of visual angle away from the center (Figure 1). To avoid ceiling effects, the luminance of notes and chords was adjusted to 8.97 cd/m^2 and 23.5 cd/m^2, and the Weber contrast was -0.957 and -0.889 respectively.

Tibetan strings were displayed in Himalaya font. Each Tibetan string subtended a horizontal and vertical visual angle of 1.23° x 1.94°. The edge of the strings was 2.2° of visual angle away from the center (Figure 1). To avoid ceiling effects, the luminance of the strings was adjusted to 25.85 cd/m^2, and the Weber contrast was -0.877.

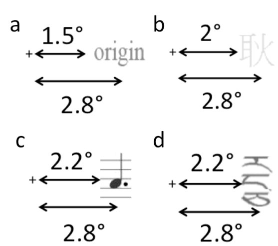

Figure 1. The position of (a) an English word and (b) a Chinese character presented in the word naming task; (c) a music note and (d) a Tibetan string presented as the first stimulus in the divided visual field sequential matching task

Experiments were conducted using E-Prime v2.0 Professional Extensions for Tobii (Psychology Software Tools, Inc.), with a Tobii T120 eye tracker (Tobii Technology) to ensure participants' central fixation. A chin rest was used to reduce participants' head movement. Calibration was performed before the start of each block. The block order was counterbalanced and trials were randomized across participants.

Procedures

In all tasks, each trial started with a fixation cross at the centre (horizontal length: 1 mm; vertical length: 2 mm). Participants' eye movement was monitored through a Tobii T120 eye tracker. After detecting the central fixation, a red box appeared around the cross. The experimenter then pressed a key to present the target stimulus. In the naming tasks, Chinese characters were presented for 90 ms whereas English words were presented for 150 ms, to minimize the possibility of the character/word being foveated. The screen then turned blank until participants' response (Figure 2). Participants were asked to read aloud the stimulus displayed either at the LVF, center (top/bottom), or RVF as soon as possible without moving their gaze away from the central fixation. The ACC was recorded by the experimenter, while the RT was measured as the time difference between the stimulus presentation onset and the participant's pronunciation onset, detected by a microphone.

In the sequential matching tasks, after detecting the central fixation, the first stimulus was presented either at the LVF, center (top/bottom), or RVF (for 100 ms for notes; for 110 ms for chords; for 170 ms for Tibetan strings), followed by a 250 ms mask. Then the second stimulus was presented at the center with the same duration as the first stimulus; the screen then turned blank until participants' response (Figure 3). Participants judged whether the two sequentially presented stimuli were the same or not as quickly and accurately as possible. Similarities of notes or chords were based on pitch only, regardless of the time value. In 'different' trials, the two stimuli differed by one note/symbol. Participants responded by pressing buttons on a response box with both hands. ACC and RT were recorded.

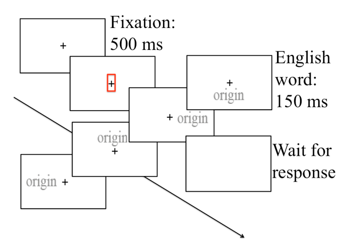

Figure 2. Procedure of the word naming task

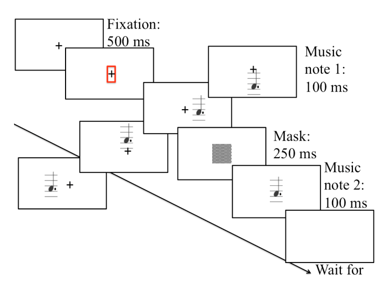

Figure 3. Procedure of the divided visual field sequential matching task

After the tasks, a demographic and music background questionnaire, English Handedness Inventory (Oldfield, 1971), Lexical Test for Advanced Learners of English

(LexTALE, Lemhofer & Broersma, 2012) and Letter–Number Sequencing task (WAIS- III, Wechsler, 1997) were conducted to assess participants linguistic background, handedness, English proficiency and working memory.

Results

Repeated measures ANOVA was used to analyze participants' ACC and correct RT. No speed-accuracy trade-off was observed. For English word naming ACC, a significant main effect of visual field was found ($F(2, 57) = 16.403$, $p < .001$). Participants performed the best when English words were presented in the RVF/LH. No other significant effect was observed in ACC. In RT, a significant interaction between VF and group was observed ($F(1, 58) = 3.347$, $p < .05$.). When we split the data by VF, musicians named English words faster than non-musicians when the words were presented in the LVF ($t(58)= -3.001$, $p < .05$) and center ($t(58)= -2.109$, $p <.05$), but not in RVF (Figure 4). When we split the data by group and examined lateralization effects, musicians named English words faster when the words were presented in the LVF than the RVF ($t(58) = 26.09$, $p < .001$), whereas non-musicians named words faster in the RVF than the LVF ($t(58) = 24.46$, $p < .001$). Thus, the two groups showed different lateralization effects in naming English words.

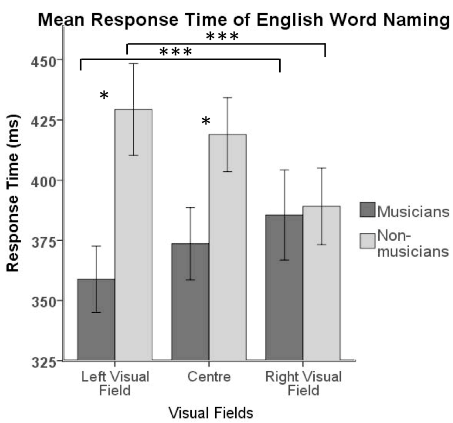

Figure 4. Mean RT of English word naming between musicians and non-musicians across three VFs (error bars: +/- 1 SE; *** $p < .001$, * $p < .05$.)

For Chinese character naming, a significant main effect of VF was found in both ACC ($F(2, 57) = 133.503$, $p < .001$) and RT ($F(2, 57) = 3.523$, $p < .05$). Participants performed the best when Chinese characters were presented in the RVF, followed by the LVF and the center; this effect did not interact with group. When we examined SP and symmetric characters separately between LVF and RVF, in ACC, a right VF advantage was found in SP characters ($F(1, 58) = 4.177$, $p < .05$), but not in symmetric characters; these effects did not interact with group. Similarly, no VF by group interaction was observed in RT (symmetric: $F(1, 58) = 2.694$, *n.s.*; SP: $F(1, 58) = .737$, *n.s.*). Thus, musicians did not perform significantly different from non-musicians in lateralization effects[2], and both groups showed more bilateral processing in Chinese than in English (Figure 5).

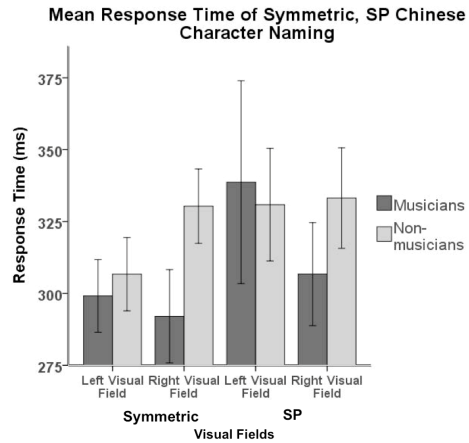

Figure 5. Mean RT of Chinese character (symmetric, SP) naming between musicians and non-musicians across two VFs (LVF and RVF) (error bars: +/- 1 SE).

For ACC in music notation reading, a significant main effect of type of notation (note vs. chord) was found ($F(1, 58) = 28.585$, $p < .001$). Participants processed notes better than chords. There was also a significant main effect of group ($F(1, 58) = 120.35$, $p < .001$): musicians showed higher accuracy than non-musicians. Also, a significant main effect of VF ($F(2, 57) = 26.877$, $p < .001$) was found. Participants performed similarly when the music notes/chords were presented in either the LVF or RVF but had the worst performance in the center. A significant interaction between type of notation and group was also found ($F(1, 58) = 13.944$, $p < .001$): musicians showed more advantage over non-musicians in note than in chord processing. For RT, a significant main effect of type of notation ($F(1, 58) = 12.984$, $p < .001$) was found: notes were processed faster than chords. Also, a significant main effect of VF ($F(2, 57) = 16.545$, $p < .001$) was found: the worst performance was observed in the center condition. There was no significant main effect in group, or significant interaction between VF and group. When we split the data by VF in separate analyses of notes and chords, musicians showed significantly faster RT than non-musicians when the notes were presented in the center ($t(58)= -2.059$, $p < .05$) and RVF/LH ($t(58)= -2.626$, $p < .05$), but not in the LVF/RH ($t(58) = -1.741$, *n.s.*; Figure 6). Thus, musicians had a significant advantage over non-musicians in the RVF/LH and center in note reading. This effect was not observed in chords.

[2] This result was further confirmed by insignificant differences in lateralization index (LVF - RVF)/(LVF + RVF) between musicians and non-musicians in both symmetric (ACC: $t(58) = .623$, *n.s*; RT: $t(50.79) = 1.937$, *n.s.*) and SP characters (ACC: $t(58) =.667$, *n.s*; RT: $t(58) = .696$, *n.s.*).

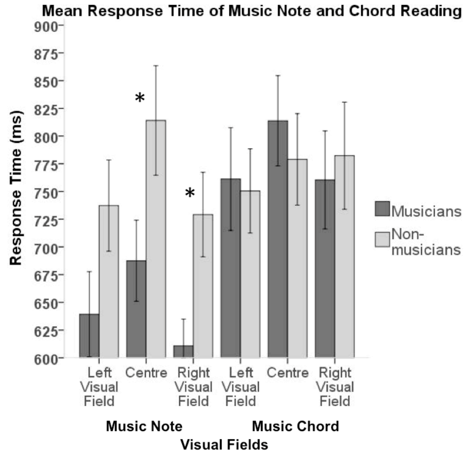

Figure 6. Mean RT in the music note and chord reading task (error bars: +/- 1 SE; * $p < .05$).

For the ACC in Tibetan strings, a significant main effect of VF was found ($F(2, 57) = 4.677$, $p < .05$): participants performed similarly when the stimuli were presented in either the LVF or RVF, and the worst in the center. There was a marginal main effect of group ($F(1, 58) = 3.922$, $p = .052$), but no interaction between VF and group. For RT, a significant main effect of VF was found ($F(2, 57) = 15.654$, $p < .001$). Participants performed the worst in the center condition. There was also no main effect of group or interaction between group and VF (Figure 7). These results suggested that musicians did not perform significantly different from non-musicians across the VF conditions.

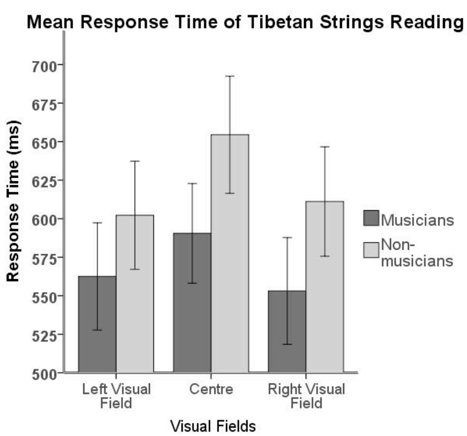

Figure 7. Mean RT in the Tibetan strings reading task. (error bars: +/- 1 SE)

Discussion

Here we examined how music reading expertise influences hemispheric lateralization effects in English word and Chinese character naming. Since English word and music notation reading expertise both involve LH lateralization, we hypothesized that musicians may show reduced LH lateralization in English word processing due to competition for LH processing resources for their music reading expertise, whereas in Chinese character processing, since it is typically more bilateral/right-lateralized than English word processing, there may be less neurocomputational resource competition between music and Chinese reading expertise. Consistent with our hypothesis, we found that in English word processing, whereas non-musicians showed a typical RVF/LH advantage in naming English words, musicians showed a LVF/RH advantage and responded significantly faster than non-musicians in both the LVF and the center position. This effect suggests facilitation of RH English word processing due to the resource competition between music notation and English word processing in the LH. In contrast, in Chinese character processing, musicians did not perform significantly different from non-musicians in lateralization effects, and both group showed more bilateral processing than in English processing.

Both English and music notation reading involves letters to phonemes conversion and note-to-sound mapping (Brown, Martinez & Parsons, 2006). This encoding process requires analytic processing, which is dominant in the LH (Hsiao & Lam, 2013). Moreover, based on the left to right reading direction, perceptual learning in both English word and music notation reading would result in a processing advantage in the RVF and LH processing advantage. Different lateralization effects between musicians and non-musicians have also been found in an ERP study, with source localization data showing musicians' bilateral activation of the fusiform (BA37) and inferior occipital gyri (BA18) for both word and music note processing; in contrast, non-musicians demonstrated activation in the left fusiform gyrus and left inferior occipital gyrus in English word processing, but had no obvious activation in the brain during music note processing (Proverbio et al., 2012). This finding is consistent with our results, showing that English word processing was more bilateral in musicians than in non-musicians, possibly due to potential neurocomputational resources competition between them.

In contrast, musicians and non-musicians show similar lateralization effects in Chinese character naming. Since Chinese character processing is more bilateral/right-lateralized as compared with English word processing, musicians who are also expert Chinese readers may be less likely to have neurocomputational resource competition with Chinese character processing. Thus, our results suggest that neurocomputational resource competition may come from processing multiple visual object categories that rely more on similar information processing mechanisms in the brain (e.g., left-laterlizaed music reading expertise and English word processing), but not in the domains that involve less overlapping neural mechanisms (e.g., left-lateralized music reading expertise and right-lateralized/ bilateral Chinese character processing). It also demonstrates that competition between different expertise domains depends on their similarities in terms of information processing requirements.

Here we also found that when a note recognition task relies purely on visual processing of note locations, both musicians and non-musicians showed bilateral processing, although musicians were more accurate and responded faster than non-musicians. This result was consistent with previous studies showing bilateral music note processing in musicians (Proverbio et al., 2012). As our task was limited to pitch judgments, it remains unclear whether reading other information (e.g. temporal information) in music notation can result in different lateralization effects between musicians and non-musicians. Also, we did not observed lateralization difference between musicians and non-musicians in chord reading. This result is in contrast to Segalowitz et al.'s (1979) study showing a strong RVF advantage in chord processing with a piano playing task that may have involved more left-lateralized motor planning. .

As for novel symbol string (i.e. Tibetan) processing, musicians and non-musicians did not show lateralization differences, which suggested they did not differ in its underlying neural mechanism. Nevertheless, a marginal advantage of musicians over non-musicians in ACC may suggest benefits from music reading in symbol processing.

To conclude, this study examined how music reading expertise influences hemispheric lateralization effects in English word and Chinese character naming. In English naming, whereas non-musicians showed a typically RVF/LH advantage, musicians showed a LVF/RH advantage and responded significantly faster than non-musicians in both the LVF and the center positions. In contrast, in Chinese character naming, musicians and non-musicians show similar lateralization effects regardless of their difference in music reading experience. This difference between English and Chinese processing may be due to stronger neurocomputational resource competition between music and English reading expertise for LH information processing as compared with Chinese reading expertise. This result suggests that music reading experience may have differential influences on the processing of different languages, depending on their similarities in the cognitive processes involved.

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