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#### **Authors**

Tze Kwan, Li  
Hei Yan Veronica, Chan  
v, Luhe  
et al.

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# How does Music Reading Expertise Modulate Visual Processing of English Words? An ERP study

Tze Kwan, Li ([saralis@hku.hk](mailto:saralis@hku.hk))

Hei Yan Veronica, Chan ([veron919@connect.hku.hk](mailto:veron919@connect.hku.hk))

Luhe Li ([rhys@connect.hku.hk](mailto:rhys@connect.hku.hk))

Janet H. Hsiao ([jhsiao@hku.hk](mailto:jhsiao@hku.hk))

Department of Psychology, University of Hong Kong  
627 Jockey Club Tower, Pokfulam Road, Hong Kong SAR

## Abstract

Music notation and English word reading have similar visual processing requirements. It remains unclear how the two skills influence each other. Here we investigated the modulation of music reading expertise on visual processing of English words through an ERP study. Participants matched English real, pseudo, and non-words preceded by musical segments or novel symbol strings in a sequential matching task. Musicians showed smaller N170 amplitude in response to English non-words preceded by musical segments than by novel symbol strings in the right hemisphere. This effect was not observed in real or pseudo-words, or in any of non-musicians' responses. Similar to English non-words, musical segments do not have morphological rules or semantic information, giving rise to this modulation effect. This finding suggested a shared visual processing mechanism in the right hemisphere between music notation and English non-word reading, which may be related to serial symbol processing as suggested by previous studies.

**Keywords:** Music reading expertise; EEG; event-related potential (ERP); English word reading

## Introduction

Recent research has shown that different perceptual expertise domains can influence each other. For example, car perception was interfered by concurrent face perception in car experts (presumably also face experts) but not in car novices, suggesting shared neural processing mechanisms between car and face recognition expertise (Gauthier, Curran, Curby & Collins, 2003). In an ERP study, Rossion, Kung, and Tarr (2004) showed that expertise with Greebles led to a decrease in N170 in response to faces with concurrent Greeble presentation, suggesting competition between expertise domains in early perceptual processing.

Similarly, music notation and English word reading expertise may influence each other due to their similarities in visual processing. For example, both music notation and English word reading involve decomposing visual input into components (i.e., letters or notes) for mapping to components in sounds (i.e., phonemes or pitches; Brown, Martinez & Parsons, 2006; Hsiao & Lam, 2013). The requirement of grapheme-phoneme conversion in English word reading has been suggested to lead to a strong left hemisphere (LH) lateralization. For example, a right visual field (RVF)/LH advantage has been found in word naming (e.g. Brysbaert & d'Ydewalle, 1990). Consistent with these findings, fMRI studies have shown a region inside the left fusiform area

responding selectively to words (e.g. McCandliss, Cohen, & Dehaene, 2003). ERP studies showed that English words elicited larger N170 amplitude in the LH than the RH in a repetition detection task (Maurer, Brandeis & McCandliss, 2005). This LH lateralization may be attributed to the left-lateralized phonological processing (Rumsey et al., 1997).

Similarly, in music notation processing, Segalowitz, Bebout, and Lederman (1979) reported a RVF/LH advantage in chord playing, which may be related to the requirement of mapping individual notes to different pitches/fingerings. Indeed, music notation and English word reading are shown to have shared neural mechanisms in the LH. For example, musicians with brain lesions in the LH showed difficulties in both music and English word reading (Hébert & Cuddy, 2006). Also, both English and music notations are read from left to right, and thus letters and music notes are recognized in the RVF more often than the left visual field (LVF) during reading, resulting in a similar RVF processing advantage due to perceptual learning (Wong & Hsiao, 2012).

While the LH is shown to play an important role in English word and music notation reading, the RH is also involved, particularly in visual form processing of words and notes. For example, in a lexical decision priming task, English word processing in the LVF/RH was shown to benefit from orthographically similar primes, whereas that in the RVF/LH benefitted from phonologically similar primes. This result suggested that the RH and the LH had differential advantages in orthographic and phonological processing of English words (Lavidor & Ellis, 2003). Consistent with this finding, English word processing in the RH has been reported to be more sensitive to variations in visual word forms. For example, the word length effect in English lexical decisions (i.e., faster and more accurate responses to shorter words) was only observed when words were presented in the LVF/RH but not the RVF/LH, suggesting that RH word processing involves more letter-by-letter recognition/serial processing than that in the LH (Lavidor & Ellis, 2001). Similarly, in music note processing, a right lateralized or bilateral visual processing mechanism has been observed. For example, fMRI studies have shown that the right occipitotemporal region was associated with music sight-reading (Schön, Anton, Roth & Besson, 2002). Bilateral activations in the fusiform and inferior occipital gyri in musicians were also reported in a note selection task. (Proverbio, Manfredi, Zani & Adorni, 2013). In a divided

visual field study, no lateralization effect was observed in sequential matching of notes and chords (Li & Hsiao, 2015).

Although previous research has suggested similarities between English word and music notation reading processes, it remains unclear how they influence each other. We have previously found that, whereas non-musicians showed a typical RVF/LH advantage in naming English words, musicians showed an LVF/RH advantage and responded significantly faster than non-musicians when words were presented in either the LVF or the center position (Li & Hsiao, 2015). This effect suggested a facilitation of RH English word processing due to music reading experiences. This phenomenon may be due to shared neural mechanisms between the two expertise domains in the LH that lead to resource competition, consequently making musicians rely more on RH processing for English word recognition. It may also be the similarities between music notation and English word reading processes in the RH accommodate each other, making the relevant processes more efficient and consequently facilitating RH English word processing.

While English word and music notation reading share similar visual processing requirements, they differ significantly in their involvement in lexical processing. More specifically, English words follow morphological and orthographic rules with clearly defined segment boundaries and lexical representations, whereas musical segments do not follow as strict sequencing rules as words and are not associated with specific semantic representations (Chan & Hsiao, 2016). Since previous research has suggested that LH English word processing is more relevant to phonological processing of English words whereas RH English word processing is more sensitive to variations in visual word forms, the modulation of music reading experience on visual processing of English words is likely to be mainly due to a shared processing mechanism in the RH. In addition, this modulation may be stronger in English non-word processing than the processing of real or pseudo-words, since non-words do not follow morphological rules or have meanings, similar to musical segments. To test these hypotheses, here we conduct an EEG study to examine how music reading expertise influences visual processing of English stimuli. A sequential matching task is used to focus on visual processing of English words. Following Rossion et al. (2004), here we examine how N170 responses to English words are influenced by the processing of music notes in musicians and non-musicians. We expect that musicians will have a stronger reduction in N170 response to English stimuli under the processing of music notes than non-musicians in the RH, particularly for English non-words.

## Methods

### Participants

Participants were 60 Cantonese (L1)-English (L2) bilinguals from Hong Kong, whose ages ranged from 18 to 29 ( $M = 21$ ,  $SD = 2.8$ ). They had similar language and college education backgrounds, with normal or corrected to normal vi-

sion. They were categorized as 30 musicians (14 males, 16 females) and 30 non-musicians (12 males, 18 females).

Musicians were well-trained pianists, who started music training at age 3-8 ( $M = 5.33$ ,  $SD = 1.47$ ). All of them were either piano teachers, music major students, or frequent piano players. They had attained grade 8 or above in the graded piano examinations of the Associated Board of The Royal Schools of Music (ABRSM), with 8-25 year experience in piano playing ( $M = 15.03$ ,  $SD = 3.89$ ) and regular music reading hours per week ( $M = 7.16$ ,  $SD = 12.33$ ). Musicians outperformed non-musicians in musicality, as assessed by the Goldsmiths Musical Sophistication Index (Müllensiefen, Gingras, Musil, & Stewart, 2014;  $t(58) = 9.97$ ,  $p < .001$ ). In contrast, non-musicians did not receive any music training.

Aside from their music background, musicians and non-musicians were closely matched in handedness and language exposure. Most participants were right-handed, which was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971;  $M: 54.33$ , 3<sup>rd</sup> right decile;  $NM: 64.33$ , 3<sup>rd</sup> right decile, *n.s.*). All participants started learning English as a second language at age 3, and have similar self-reported English reading hours ( $M: 27.48$ ;  $NM: 18.77$ ; *n.s.*). No participants had experience with the Tibetan language.

### Materials

Materials consisted of 3 types of English words (real, pseudo, and non-words with 4-6 letters) as target stimuli and two types of comparable pre-/post-stimulus masks: musical segments with 4 random notes without clefs ( $n = 1323$ ) ranging from D4 to G5 and Tibetan letter strings with 4 random letters ( $n = 1323$ ). Tibetan letter strings, a novel stimulus type that no participants had any experience with, were included as a control condition.

English real words ( $n = 126$ ) were selected from the SUBTLEX-US corpus (Brysbaert, New & Keuleers, 2012) and Wuggy (a word generator, Keuleers & Brysbaert, 2010). To control information distribution within a word, the same number of high-frequency words and low-frequency words were selected within the informative beginning and informative end subsets in Bryden, Mondor, Loken, Ingleton & Bergstrom (1990). Word frequency was closely matched between 'same' and 'different' trials in the matching task and between music and Tibetan conditions. For 'same' trials, two target stimuli were identical. For 'different' trials, half trials had shared beginnings (e.g. banker, banner), while the other half had shared ends (e.g. salary, notary).

English pseudo-words (i.e. non-existing words with legal letter strings at the word beginning and word end,  $n = 126$ ) were created by extracting and recombining word beginnings and ends from our English real word list. This is to control information distribution at the word beginnings and ends between real and pseudo-word stimuli. For 'same' trials, two target stimuli were identical. For 'different' trials, half trials had shared beginnings (e.g. banher, banord), while the other half had shared ends (e.g. saliew, supiew).

English non-words (i.e., illegal letter strings,  $n = 126$ ) were created by re-ordering the letters in the word begin-

nings and word ends from our English pseudo-word list such that the letter combinations do not follow morphological rules in English. This is to closely match the letters used in all conditions. For ‘same’ trials, two target stimuli were identical. For ‘different’ trials, half trials had shared beginnings (e.g. nbaerh, nbaodr), while the other half had shared ends (e.g. alsuwe, spuiwe). The non-words were checked against the morphologically ambiguous syllables in the ARC Nonword database (Rastle, Harrington, & Coltheart, 2002) to ensure their suitability for our task.

### Design

To focus on visual processing of English words, a sequential matching task similar to Gauthier et al. (2003) was used. The design consisted of 2 within-subject variables: English word type (real/pseudo/non-words), stimulus mask (musical segments vs. Tibetan letter strings), and 1 between-subject variable: group (musicians vs. non-musicians). In the ERP data analysis, an additional variable hemisphere (LH vs. RH) was included. Participants completed the task with English real, pseudo, and non-word stimuli with either musical segment or Tibetan letter string masks (Fig. 1). For each mask type, 36 ‘same’ and 36 ‘different’ trials were included for each word type condition. Half of the stimulus pairs in ‘same’ and ‘different’ trials were different in the two mask conditions to avoid practice effects.

English words were displayed in Courier (a serif font with fixed width) to ensure constant center-to-center spacing between letters. Under the viewing distance 50 cm, each English word subtended a horizontal and vertical visual angle of 4.06° x 0.95° (4 letters), 5° x 0.95° (5 letters) and 6.35° x 0.95° (6 letters). Musical segments with 4 random notes in crotches (1 beat) with the five-line staff subtended a horizontal and vertical visual angle of 6.90° x 1.62°. Tibetan letter strings with 4 random letters were presented in Himalaya font and subtended a horizontal and vertical visual angle of 6.90° x 1.62°. All stimuli were presented in black with a white background on a CRT monitor. Experiments were conducted using E-Prime v2.0 with 64-channel ANT EEG recording. A chinrest was used to reduce head movement. The block and trial orders were randomized.

### Procedure

Each trial started with a central fixation with a randomly determined presentation duration between 400-600 ms. A pre-stimulus mask (a musical segment or a Tibetan letter string) was presented for 600 ms, followed by an 800 ms presentation of the first target stimulus (a real/pseudo/non word). Then, a post-stimulus mask (a musical segment or a Tibetan letter string) was presented for 600 ms, followed by an 800 ms presentation of the second target stimulus (a same or different real/pseudo/non-word; Fig. 1). All stimuli were presented at the center of the screen. Participants judged whether the two target stimuli were the same or not by pressing buttons with both hands. The trial did not proceed to the 800ms ‘blink’ period until receiving partici-

pants’ response. Accuracy (ACC) and response time (RT) were recorded by Eprime with EEG recording.

Prior to the English word sequential matching task, a demographic and music background questionnaire, the Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2014) and Edinburgh Handedness Inventory (Oldfield, 1971) were conducted to assess participants’ language, music background, and handedness.

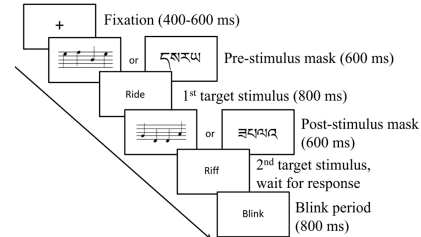


Fig. 1. Procedure of the English word sequential matching

### Results

In the English word sequential matching task, no significant difference was observed between musicians and non-musicians in ACC and RT of matching real (M: 97.27%, 606.02 ms; NM: 94.31%, 774.41 ms), pseudo (M: 97.04%, 619.90 ms; NM: 93.29%, 698.58 ms) and non-words (M: 95.88%, 598.58 ms; NM: 91.20%, 727.38 ms), suggesting that they had a similar performance level in the task.

The 64-channel EEG data were analyzed using EEGLAB (Delorme & Makeig, 2004) and ERPLAB (Lopez-Calderon & Luck, 2014) in MATLAB. Bin-based epochs were extracted from -100 ms to 600 ms of the stimulus onset and corrected from baseline deviations using a pre-stimulus window of 99 ms. The analyses of the N170 component were based on the electrode pairs with the largest N170 amplitude from the grand average data. Accordingly, electrodes PO7 (LH) and PO8 (RH) were selected for the analysis of N170 response to the pre-stimulus masks (musical segments vs. Tibetan letter strings), while electrodes P7 (LH) and P8 (RH) were selected for N170 responses to the first presentation of the English real, pseudo, and non-words preceded by musical segments or Tibetan letter strings, using repeated measures ANOVA. Note that we only analyzed the N170 responses to the first presentation of the English word stimuli since the EEG responses to the second stimulus may be contaminated by button responses..

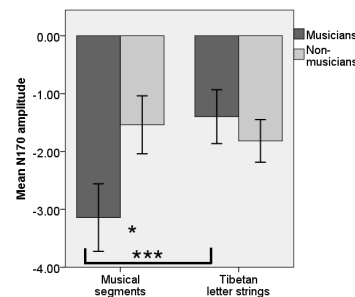


Figure 2. Average N170 amplitude at PO7 and PO8 in response to musical segments and Tibetan letter strings (error bars = +/- 1 SE; \*\*\*  $p < .001$ , \*  $p < .05$ ).

In the ERP response to the pre-stimulus mask, a significant interaction between mask type (music vs. Tibetan)  $\times$  group (musicians vs. non-musicians) was observed,  $F(1, 52) = 31.80, p < 0.001$ : musicians had a larger N170 amplitude than non-musicians in response to musical segments,  $t(52) = -2.07, p = .044$  (Fig. 2), whereas no difference was observed between the two groups in response to Tibetan letter strings. When we split the data by group, musicians had a larger N170 amplitude in response to musical segments than to Tibetan letter strings,  $F(1, 27) = 68.98, p < 0.001$  (Fig. 2), whereas non-musicians did not show any significant differences in response to musical segments and Tibetan letter strings. These findings were consistent with the perceptual expertise literature showing that visual expertise increases the N170 amplitude in response to the stimuli in experts as an expertise marker (Rossion et al., 2004). No main effects or interactions with hemisphere were observed (Fig. 3).

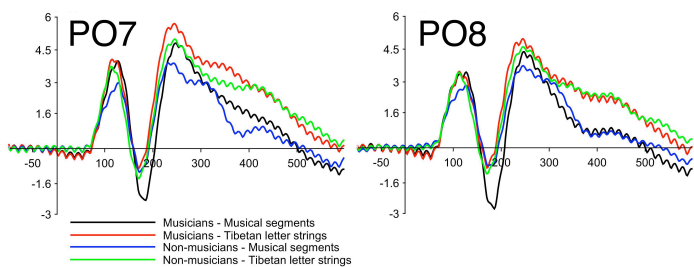


Figure 3. N170 amplitude in response to musical segments and Tibetan letter strings between musicians and non-musicians in PO7 (LH) and PO8 (RH).

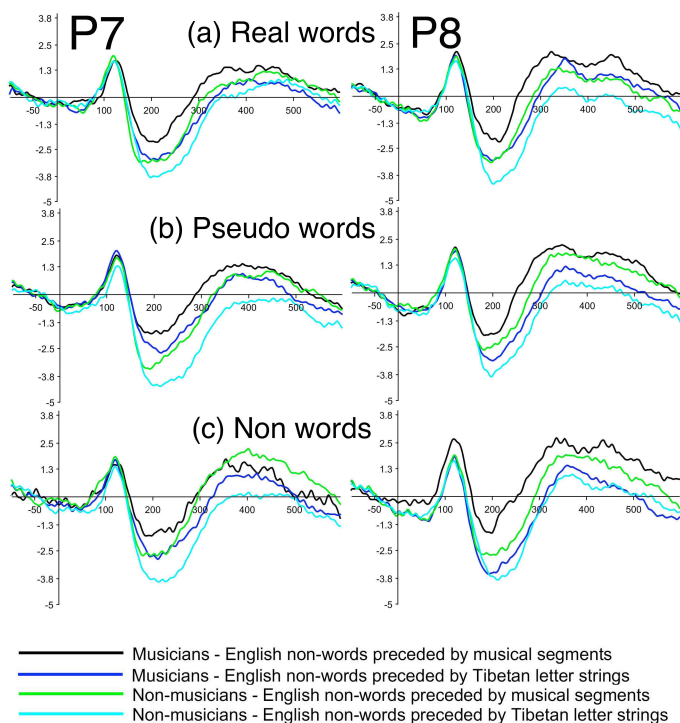


Figure 4. N170 amplitude in response to English (a) real, (b) pseudo and (c) non-words preceded by musical segments and Tibetan letter strings between musicians and non-musicians in P7 (LH) and P8 (RH) in sequential matching.

For N170 responses to English words (the first target stimulus), a significant four-way interaction, mask type (music vs. Tibetan)  $\times$  word type (real vs. pseudo vs. non-words)  $\times$  hemisphere (LH vs. RH)  $\times$  group (musicians vs. non-musicians), was observed,  $F(2, 53) = 3.32, p = .044$ . To better understand this interaction, we examined the N170 amplitude in response to real, pseudo, and non-words separately (Fig. 4). A significant interaction among mask type, hemisphere, and group was found in English non-words,  $F(1, 54) = 6.27, p = .015$ , but not in real or pseudo-words. This three-way interaction suggested that musicians and non-musicians had different N170 amplitudes in response to non-words preceded by musical segments and Tibetan letter strings in the LH and the RH. This effect was not found in real or pseudo-words.

When we examined the data of non-words in two participant groups separately, musicians showed a significant interaction between mask type (music vs. Tibetan) and hemisphere (LH vs. RH),  $F(1, 26) = 10.60, p = .003$ , whereas non-musicians did not. When we examined musicians' data in the two hemispheres separately, a significant main effect of mask type (music vs. Tibetan) was observed,  $F(1, 26) = 9.004, p = .006$ : musicians had a smaller N170 amplitude in response to English non-words preceded by musical segments ( $-2.17\mu V, SD = 3.88$ , Fig. 5) than those preceded by Tibetan letter strings in the RH ( $-4.11 \mu V, SD = 2.11$ ). This mask type effect was not observed in the LH. Note that this mask type effect was also not observed in either participants' N170 responses to real and pseudo-words, or non-musicians' N170 responses to non-words. This phenomenon demonstrates a modulation of musicians' musical segment processing on English non-word processing in the RH.

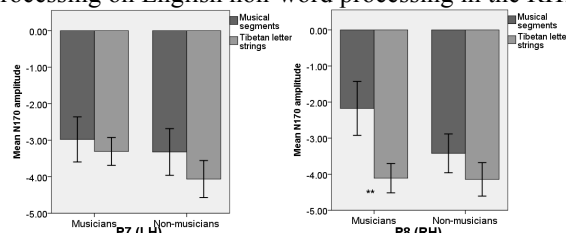


Figure 5. Musicians had a greater reduction in N170 amplitude in response to non-words preceded by musical segments than that preceded by Tibetan letter strings in the RH. No reduction effect was observed in the LH or in non-musicians. (error bars =  $\pm 1 SE$ ;  $** p < .01$ ).

## Discussion

Here we examined how music reading expertise influences visual processing of English stimuli. Since music notation reading does not involve semantic processing as English word reading does, we hypothesized that the modulation of music reading experience on English word processing would be mainly in the RH, which is shown to be important for visual form processing of English words. In addition, the modulation would likely be stronger in English non-word processing than the processing of real or pseudo-words, since similar to musical segments, non-words do not follow morphological/orthographic rules. Consistent with our hy-

potheses, we showed that musicians had a reduced N170 amplitude in response to English non-words preceded by musical segments as compared with that preceded by novel symbol strings in the RH, whereas non-musicians showed no difference in N170 response to non-words preceded by either musical segments or Tibetan letter strings. In addition, this reduction in N170 in musicians was only observed in non-words, but not in real or pseudo-words. This result suggests a shared neural mechanism between English non-word and musical segment processing in the RH.

The RH N170 modulation effect of musical segments in musicians was only observed in English non-words but not in real or pseudo-words. This effect suggests that the interaction between visual English word and music notation processing depends on the similarities of the cognitive processes involved. More specifically, in contrast to English real and pseudo-words, non-words and musical segments do not follow any morphological or orthographic rules (Chan & Hsiao, 2016). Given that they share similar global forms, containing components of similar sizes arranged horizontally, their recognition may both rely on component by component serial processing, giving rise to the modulation effect. Consistent with this speculation, a RH advantage in the perception of global forms has been consistently reported (Sergent, 1982). English word processing in the RH is also shown to be more sensitive to variations in visual word forms than the LH, such as words in case alternation (Lavidor & Ellis, 2001). In particular, Lavidor and Ellis (2001) found that the word length effect in English lexical decisions (i.e., faster responses to shorter words) was observed only when words were presented in the LVF/RH but not in the RVF/LH. However, when words in MiXeD CaSe were used, encouraging letter-by-letter processing, the word length effect was observed in both visual fields. These results suggest a letter-by-letter, serial processing engaged in the RH word recognition, in contrast to a left-lateralized automated, whole-word lexical processing unaffected by word lengths (see also Lavidor, Ellis, & Pansky, 2002). Similarly, patients with LH lesions retained letter-by-letter reading ability, suggesting that the nature of RH word processing involves letter-by-letter recognition (Cohen et al., 2004). Our results here were consistent with these findings, suggesting that RH English word processing was modulated by music notation reading experience due to their similarity in letter-by-letter or note-by-note visual processing. Consistent with our finding, in an fMRI study, Proverbio et al., (2013) reported that musicians recruited the right fusiform gyrus and the right inferior occipital gyrus in an orthographic letter recognition task, whereas non-musicians showed activations at the corresponding regions in the LH. This finding again suggests that music reading expertise modulates English word reading in the RH.

This RH modulation effect of music reading expertise was also consistent with our recent study showing that musicians named English words faster than non-musicians when words were presented in the LVF/RH (Li & Hsiao, 2015). More specifically, this LVF/RH advantage in word naming

in musicians may be due to the facilitation of shared neural information processing mechanisms in the RH between music notation and English word reading, resulting in a transfer effect from music note to English word processing in the RH. Note that in the current study, the lack of the N170 modulation effect in real and pseudo-words does not necessarily mean that this modulation from music notation reading experience does not affect real word and pseudo-word processing. English word recognition involves the processing of visual word forms, phonology, and semantics. While the LH is shown to involve critically in lexical processing, the RH is reported to be important for the processing of visual word forms. Our current results suggest that the modulation of music experience is mainly in the RH. Since the processing of real and pseudo-words involves both visual word form and lexical/sublexical processing, these lexical effects may also influence N170 amplitudes measured in both hemispheres. Indeed, Ziegler et al. (1997) showed that real and pseudo-words elicited more negative early visual ERPs than non-words in bilateral posterior regions in a lexical decision task, with this difference appearing earlier in the LH than the RH. Thus, the RH N170 modulation effect of music reading expertise may have been contaminated by lexical/sublexical effects in real and pseudo-word processing. It is also possible that the lack of the modulation effect in real and pseudo-word processing is because random musical segments were used. Future work will examine whether musical segments from real musical pieces (motifs) will have different modulation effects.

Note also that the current results do not rule out possible modulation effects of music reading experience on phonological processing of English words, since our task, sequential matching, involved mainly visual word processing. Previous studies have reported benefits of music training on the phonological processing of English words, as shown in phonological skill training (Degé & Schwarzer, 2011). Thus, musicians' LVF/RH advantage in English word naming over non-musicians observed in our previous study (Li & Hsiao, 2015) could also be related to modulation effects of music reading experience on English phonological processing in the LH. Future work will examine this possibility.

In short, here we show that music notation and English non-word processing share similar neural mechanisms in the RH, as demonstrated in the reduced N170 responses to English words under the processing of musical segments. This effect was not observed in real or pseudo-words. Similar to English non-words, musical segments do not follow orthographic rules. Their processing may rely on serial processing of horizontally arranged components of similar sizes, giving rise to the modulation effect. This effect demonstrates that the interaction between different perceptual expertise domains depends on the similarities of the cognitive processes involved. Future work may use Korean Hangul stimuli, in which letters are arranged into a square shape instead of horizontally, to examine whether the modulation effect of music reading expertise in the RH was restricted to words with a global form similar to music notations (i.e.,

components of a similar size arranged horizontally) or could be applied to words in alphabetic languages in general.

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