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Music-reading expertise modulates the visual span for English letters but not Chinese characters

Sara T. K. Li
Department of Psychology, University of Hong Kong,
Hong Kong, SAR

Susana T. L. Chung
School of Optometry, University of California Berkeley,
Berkeley, CA, USA

Janet H. Hsiao
Department of Psychology, University of Hong Kong,
Hong Kong, SAR

Recent research has suggested that the visual span in stimulus identification can be enlarged through perceptual learning. Since both English and music reading involve left-to-right sequential symbol processing, music-reading experience may enhance symbol identification through perceptual learning particularly in the right visual field (RVF). In contrast, as Chinese can be read in all directions, and components of Chinese characters do not consistently form a left-right structure, this hypothesized RVF enhancement effect may be limited in Chinese character identification. To test these hypotheses, here we recruited musicians and nonmusicians who read Chinese as their first language (L1) and English as their second language (L2) to identify music notes, English letters, Chinese characters, and novel symbols (Tibetan letters) presented at different eccentricities and visual field locations on the screen while maintaining central fixation. We found that in English letter identification, significantly more musicians achieved above-chance performance in the center-RVF locations than nonmusicians. This effect was not observed in Chinese character or novel symbol identification. We also found that in music note identification, musicians outperformed nonmusicians in accuracy in the center-RVF condition, consistent with the RVF enhancement effect in the visual span observed in English-letter identification. These results suggest that the modulation of music-reading experience on the visual span for stimulus identification depends on the similarities in the perceptual processes involved.

Introduction

Recent research has shown that experts have perceptual and cognitive abilities superior to novices in tasks related to their expertise, such as in chess playing (Reingold, Charness, Pomplun, & Stampe, 2001), in sports (see Gegenfurtner, Lehtinen, & Säljö, 2011; Mann, Williams, Ward, & Janelle, 2007 for meta-analyses) and in medical diagnosis (Manning, Ethell, Donovan, & Crawford, 2006). In these studies, experts typically demonstrated superior response accuracy, shorter response time (RT), fewer eye fixations, shorter fixation durations, or a larger visual span in the tasks.

Visual span has been defined as the size of the region around the fixation point in which letters/visual stimuli can be reliably recognized in one fixation without using any contextual information (Jacobs, 1986; Legge, Ahn, Klitz, & Luebker, 1997; Legge, Cheung, Yu, Chung, Lee, & Owens, 2007; O'Regan, Lévy-Schoen, & Jacobs, 1983). Legge, Mansfield, and Chung (2001) developed a "trigram paradigm" to measure the size of the visual span for English letters according to participants' letter recognition accuracy for trigrams (random letter strings with three letters, e.g., tgu) that were presented horizontally either on the left (negative positions) or on the right (positive positions) from the midline (0) with various horizontal visual angles. To further understand the importance of visual span on reading performance, Legge et al. (2007) proposed the visual span hypothesis, which posits that the larger the size of the visual span, the higher the reading speed in word reading, as measured with the Rapid Serial Visual Presentation (RSVP) paradigm (using number of words per minute as the unit). They found that a one-letter increase in visual span was associated with a 39% increase in reading speed.

The size of visual span can be enlarged through perceptual learning, as shown in young adults (Chung, Legge, & Cheung, 2004) and older adults (Yu, Cheung, Legge, & Chung, 2010). Both studies had shown that

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participants who received letter recognition training at either the upper or lower visual field in a trigram paradigm resulted in an enlarged visual span in both trained and untrained positions, accompanied by a higher RSVP reading speed. Similar to perceptual learning, expertise training was also reported to enlarge one's visual span when reading meaningful materials related to their expertise. For example, chess experts were found to have a larger visual span in structured chess configuration detection than novices (Reingold et al., 2001), suggesting that experts are able to extract more information from one fixation in the field of expertise than novices. Musicians with extensive music-reading experiences were also found to have a larger reading span than poor readers of music notations. For example, one study found that well-trained musicians had a span of 6.5 notes, whereas the poorest reader only read 3.5 notes at a time (Sloboda, 1974).

Music reading involves mapping a set of spatially distributed notes and chords on a staff to a horizontal melodic line. Musicians process musical information in the horizontal and vertical direction during music reading: In the horizontal direction, musicians focus on melodic contour and read further ahead from left to right to ensure in-time playing (Goolsby, 1994). Previous studies have suggested that musicians read music scores according to a group of notes (i.e., chunks; a larger unit; Goolsby, 1994; Sloboda, 1976, 1977; Waters, Underwood, & Findlay, 1997; Wolf, 1976) or in a note-by-note manner according to note functions (e.g., when G-B was presented as a major third; Goolsby, 1994). In the vertical direction, music reading varies according to the type of instruments. For example, pianists attempt to read two staffs at the same time, whereas violinists only read one staff. In general, musicians read musical markings below staff without making an eye fixation. Musicians also adjust their reading strategies according to the musical textures, suggesting the flexibility of musicians in music reading across different musical textures. As reported in Rayner (1998), Weaver (1943) suggested that pianists focused more on the horizontal melodic lines in contrapuntal and polyphonic music, which contains multiple melodic lines. In contrast, musicians have more vertical fixation sequences when reading homophonic and chordal music, which contains different vertical chord progressions. These findings suggest that musicians may attempt to perceive as much information as possible through both horizontal and vertical peripheral vision (Goolsby, 1994), and consequently develop a larger visual span in both directions in music-reading tasks.

In addition to reading music, music-reading expertise may also influence the visual span in language reading due to some similarities in the perceptual processes involved. For example, both music and English reading involve processing horizontally arranged symbols from left-to-right, and thus readers constantly anticipate new stimuli appearing in the right visual field (RVF) during reading. Consequently, word stimuli are recognized in the RVF more often than the left visual field (LVF), resulting in processing advantages in the RVF/left hemisphere (LH) through perceptual learning (Brysbaert & Nazir, 2005; Wong & Hsiao, 2012). Indeed, studies examining visual field differences in English word and music note processing typically reported an RVF/LH advantage (e.g., Brysbaert & d'Ydewalle, 1990; Segalowitz, Bebout, & Lederman, 1979). In addition, English word reading involves grapheme-phoneme mapping, similar to the note-to-sound mapping required in music-notation reading (Brown, Martinez, & Parsons, 2006; Hsiao & Lam, 2013). Both types of mapping involve local/analytic perceptual processing to decompose visual stimuli into components for mapping to sound components, which is shown to be more LH lateralized (e.g., Bradshaw & Nettleton, 1981; Hébert & Cuddy, 2006; Hsiao & Lam, 2013; Segalowitz et al., 1979). Consistent with this observation, patients with music-reading difficulties due to LH brain damage also showed English word reading problems (Hébert & Cuddy, 2006), suggesting that music-notation and English-word reading involve similar neural mechanisms. Thus, music-reading expertise may particularly influence the visual span in the RVF for English reading due to their similar left-to-right sequential symbol processing direction and analytic processing advantages in the RVF/LH.

In contrast to left-to-right music and English reading, Chinese can be read in all directions (left to right, right to left, or vertically). Moreover, 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. Consequently, Chinese character recognition may involve less left-lateralized analytic perceptual processing as compared with word recognition in alphabetic languages such as English (e.g., Hsiao & Lam, 2013). Consistent with this speculation, a LVF/right hemisphere (RH) advantage is typically observed in orthographic processing of Chinese characters (e.g., Tzeng, Hung, Cotton, & Wang, 1979; Yang & Cheng, 1999; Tan et al., 2001). Brain imaging studies typically showed more bilateral or right-lateralized activation in the visual area in Chinese character processing as compared with English word reading (e.g., Tan et al., 2000; Tan, Laird, Li, & Fox, 2005). In addition, in contrast to the recognition of musical segments or English words, where symbols are always horizontally arranged, components in a

a	b	c	d	e	f	g
們	杏	圖	飛	廣	風	遠

Figure 1. Examples of Chinese characters where components are arranged in different configurations: (a) left-right, (b) top-bottom, (c) concentric, (d) upper-right and below, (e) upper-left and below, (f) partially-enclosed, and (g) lower-left and above.

Chinese character can be arranged in different configurations, including left-right (Figure 1a), top-bottom (Figure 1b), concentric (i.e., an enclosed structure; Figure 1c), upper-right and below (i.e., a radical occupies the whole right-side and top part of the character; Figure 1d), upper-left and below (i.e., a radical occupies the whole left-side and top part of the character; Figure 1e), partially-enclosed (i.e., a radical occupies the top, left, and right-side of the character; Figure 1f), and lower-left and above (i.e., a radical/a major component occupies the whole left-side and bottom part of the character; Figure 1g; see Hsiao & Shillcock, 2006 for more information). Thus, readers' attention distribution during musical segment or English word recognition may be fundamentally different from that during Chinese character recognition. These phenomena suggest that music-reading expertise may have limited influence on Chinese reading due to their differences in possible reading directions, symbol/component arrangement, and perceptual processes involved.

In this study, we recruited musicians and nonmusicians, who read Chinese as their first language (L1) and English as their second language (L2), to examine how music-reading expertise modulates the visual span for music note identification, as well as for English letter and Chinese character identification. We also investigated whether music-reading expertise modulates the visual span for identifying novel symbols (i.e., Tibetan letters).

Hypothesis

We hypothesize that musicians would have a larger visual span than nonmusicians in music note identification due to an expertise effect. As for English letter identification, musicians may have a larger visual span than nonmusicians particularly in the RVF due to the similar left-to-right sequential symbol processing required in both music and English reading. More specifically, musicians who are also expert English readers may have processed horizontally arranged symbols more often in the RVF/LH through extensive music reading, which may facilitate perceptual processing of symbols with similar arrangements particularly in the RVF/LH and consequently benefit English letter identification in the RVF. In contrast, for Chinese character identification, musicians and nonmusicians may not differ in the visual span due to the dissimilarities in perceptual processes involved in music and Chinese reading. More specifically, musicians' RVF processing advantage in the perception of horizontally arranged symbols may not facilitate the perception of Chinese characters in the RVF, as Chinese can be read in all directions (left to right, right to left, or vertically), and components of Chinese characters can be arranged in different configurations within a character (e.g., top-bottom, concentric, etc., in addition to left-right). Here we also examine whether musicians have a larger visual span for novel symbol identification (i.e., Tibetan letters) due to a general processing advantage in symbol perception. In addition, since some musicians such as pianists have to read two lines of music notations simultaneously, it is possible that the facilitation of music-reading experience on the visual span for English letter identification can be extended to the vertical dimension in addition to the horizontal dimension of the visual field. To test these hypotheses, in contrast to previous studies using the "trigram paradigm" (Chung et al., 2004; Legge et al., 2001; Yu et al., 2010; cf. Pelli et al., 2007; Levi, Song, & Pelli, 2007), which only accounted for horizontal crowding effects due to the focus on measuring the horizontal visual span, we here conducted an identity-matching task to assess both the horizontal and vertical visual span with 6 × 6 testing positions. Participants were asked to attend to a briefly presented screen filled with music notes, English letters, Chinese characters, or Tibetan letters, and match a target stimulus presented at a given location afterwards. We examined how musicians and nonmusicians differ in their performance (A preliminary version of the study was published in Li, Chung, and Hsiao, 2016).

Methods

Participants

Participants were 64 Chinese-English bilinguals from Hong Kong, whose ages ranged from 18 to 29 ($M = 22.17$, $SD = 2.85$). All participants read Chinese as their first language (L1) and English as their second language (L2) from age 3. They had similar linguistic and college education backgrounds. Subjects were categorized into two groups according to their music training background: musicians (M) and nonmusicians (NM), with 16 males and 16 females in each group. Musicians were well-trained pianists, who started music training at age 3–10 ($M = 4.88$, $SD = 1.79$). All of them were piano teachers, music undergraduate/postgraduate 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) or equivalent, with 8-to-25-year experience in piano playing ($M = 16.25$, $SD = 4.15$) and regular music-reading hours per week ($M = 9.30$, $SD = 11.48$). In contrast, nonmusicians did not receive any formal music training since birth and were not able to read music notations. To further assess the overall proficiency of music reading between musicians and nonmusicians, participants were asked to rate the familiarity of a music note (crotchet D5, i.e., the D note at the fourth line on the staff) on a 10-point Likert scale. From that, musicians were found to be much more familiar with the music notes as compared with nonmusicians (M = 9.72, NM = 3.03; $t(62) = 15.637$, $p < 0.001$, $d = 3.911$, i.e., a rather large effect size according to Cohen, 1988).

Aside from their music training background, musicians and nonmusicians were closely matched in other aspects, detailed as follows. All participants were right-handed, as assessed using the Edinburgh Handedness Inventory (Oldfield, 1971; M = 75.78, 5th right decile; NM = 70.00, 4th right decile, $t(62) = 1.295$, *ns*). Both musicians and nonmusicians had normal or corrected-to-normal visual acuity (20/20) as shown in the Freiburg Visual Acuity and Contrast Test (FrACT; Bach, 2006; M = 1.27; NM = 1.33, $t(62) = -1.043$, *ns*). Both groups' verbal- and spatial-working-memory performance were matched in an N-back task (Lau, Eskes, Morrison, Rajda, & Spurr, 2010), as shown in the accuracies (Verbal: M = 87.50%; NM = 79.60%, $t(62) = 1.863$, *ns*; Spatial: M = 81.71%; NM = 74.00%, $t(62) = 1.746$, *ns*) and response times (RT; Verbal RT: M = 1045.24; NM = 1123.16, $t(62) = -1.069$, *ns*; Spatial RT: M = 1229.44; NM = 1200.95, $t(62) = 0.377$, *ns*) of the N-back task (Lau et al., 2010).

All participants started learning English as a second language at around age 3 ($M = 3.4$, $SD = 1.57$), and shared similar reading hours per week of English text (M = 17.44; NM = 17.41, $t(62) = 0.008$, *ns*) and Chinese text (M = 19.16; NM = 24.34, $t(62) = -1.204$, *ns*). Despite similar language exposure, musicians had a much higher proficiency in English and Chinese than nonmusicians, as shown in the Lexical Test for Advanced Learners of English (LexTALE, Lemhöfer, & Broersma, 2012; M = 75.65%; NM = 66.21%; $t(62) = 3.287$, $p = 0.002$, $d = 0.822$, i.e., a large effect size) and the matriculation public examinations of Chinese Language in Hong Kong (HKCEE/ HKALE/ HKDSE; M = 4.93; NM = 4.23; $t(50.739) = 2.174$, $p = 0.034$, $d = 0.0564$, i.e., a medium effect size). To rule out the possible influence from language proficiency on our data analysis, participants' English and Chinese proficiency were included as covariates in ANalysis of COVAriance (ANCOVA). No participants had any experiences with the Tibetan language.

Figure 2. Examples of (a) English lower-case letters (all letters were fit tightly into a 0.47° × 0.76° rectangular background), (b) Chinese characters (0.72° × 0.76°), (c) music notes (1.19° × 2.25° with its corresponding five-line staff) and (d) Tibetan letters (all letters were fit tightly into a 0.72° × 1.25° rectangular background) in the identity-matching task. The stimuli in this figure were shown in their relative sizes among the four types of stimuli.

This study has been approved by the Human Research Ethics Committee for Non-Clinical Faculties, University of Hong Kong and adhered to the Declaration of Helsinki.

Materials

The materials consisted of four types of stimuli: English letters (in Courier, a serif font), Chinese characters (in Microsoft DF-Hei font, a sans-serif font), music notes, and Tibetan letters (in Himalaya font). English lower-case letters (a–z, $n = 26$; Figure 2a) were used. Chinese characters ($n = 4805$; Figure 2b) were selected from the *List of Graphemes of Commonly-used Chinese Characters* (Chinese Language Education Section, HKSAR, 2012), comprising Chinese characters in various structures ranging from low to high number of strokes ($M = 12$, range = 1–32) and frequency of occurrence according to Ho's (1998) database ($M = 143.36/660000$, range = 1–24414/660000). In addition to the identity-matching tasks with English letters and Chinese characters, we also included an identity-matching task with music notes as an expertise task, and a Tibetan letter matching task to examine whether musicians' expertise in processing music notes can be transferred to novel symbol processing. As for music notes ($n = 11$; Figure 2c), crotchets (1 beat) ranging from D4 (i.e., the D note below the first line of the staff) to G5 (i.e., the G note above the fifth line of the staff) were included. Tibetan letters ($n = 45$; Figure 2d) were included as novel symbols.

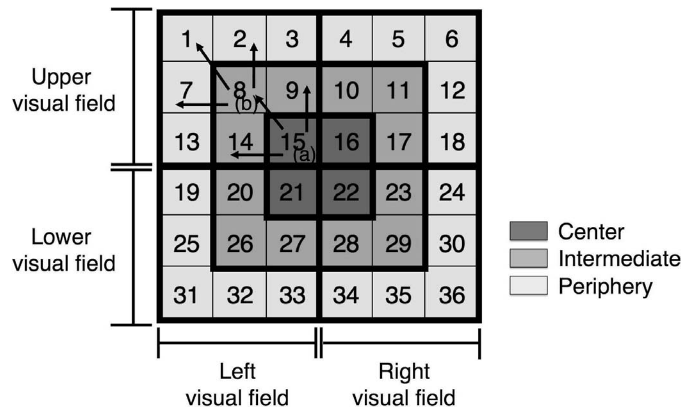


Figure 3. The 12 visual field regions used in the current study obtained through dividing 6 (horizontal) × 6 (vertical) testing positions around a central fixation mark according to eccentricity (center, intermediate, and periphery), horizontal visual field (left and right), and vertical visual field (upper and lower). The actual size of the testing positions varied according to the size of English/Chinese/music/Tibetan stimuli. Two sets of arrows showed the progression rules applied to (a) positions at the center when advancing to the intermediate level, and (b) positions at the intermediate level when advancing to the periphery according to the progressive testing paradigm in the task.

Design

In the current study, we aimed to examine the difference between musicians and nonmusicians in their visual span for identifying visual stimuli due to their difference in music-reading experience. Participants performed identity-matching tasks with four types of stimuli: English letters, Chinese characters, music notes, and Tibetan letters. In each task, we defined each participant's visual span as the area in the visual field where above-chance identity-matching performance was achieved. To assess the size of the area, we divided the visual field on three dimensions: eccentricity (center vs. intermediate vs. periphery), horizontal visual field (left vs. right), and vertical visual field (upper vs. lower), resulting in 12 visual field regions and 36 testing positions in total as shown in Figure 3. We then counted the number of visual field regions where each participant had an above-chance performance to assess the visual span, separately for each eccentricity and horizontal-visual-field condition (i.e., central LVF, central RVF, intermediate LVF, intermediate RVF, peripheral LVF, and peripheral RVF) to examine the visual span relevant to our hypothesis about a possible RVF advantage. We then compared the counts between musicians and nonmusicians using chi-square tests. In addition, we examined participants' accuracy and correct response time (RT) in different eccentricity and horizontal-visual-field conditions using ANCOVA (with participants' English/Chinese proficiency as a covariate) with Greenhouse-Geisser correction applied for violation of sphericity and Bonferroni correction applied for multiple comparisons. More specifically, the ANCOVA design consisted of a between-subject variable: group (musician vs. nonmusician), and two within-subject variables: eccentricity (center vs. intermediate vs. periphery) and horizontal visual field (left vs. right).

A progressive testing design was used such that participants started with stimulus identity matching in the easiest, center condition, and progressed to the next eccentricity level (i.e., the intermediate condition, and then the periphery condition) only if they achieved above-chance performance (0.5 identity-matching accuracy based on a yes/no response; see Procedure for more information) at an adjacent testing position at the current eccentricity level. More specifically, as shown in Figure 3, participants started from the four positions at the center (position 15, 16, 21, 22), followed by the 12 positions at the intermediate (position 8–11, 14, 17, 20, 23, 26–29), and then to the 20 positions at the periphery (position 1–6, 7, 12, 13, 18, 19, 24, 25, 30, 31–36). If above-chance accuracy was achieved at a testing position in the center condition, the participant would progress to the adjacent testing positions in the intermediate condition. For example, an above-chance level performance at position 15 (Figure 3, location a) would proceed to position 8, 9, and 14 in the intermediate condition. Similarly, an above-chance accuracy at a testing position in the intermediate condition would progress to the adjacent testing positions in the periphery condition. For example, an above-chance accuracy at position 8 (Figure 3, location b) would progress to position 1, 2, and 7 at the periphery. In each eccentricity condition, stimuli were presented at different testing positions randomly. The experiment was terminated when a participant was not able to proceed to any adjacent positions at the next eccentricity level. This progressive testing design was used so that when participants already had a below-chance-level performance at one eccentricity level, they were not required to progress to a more difficult level (i.e., farther away from central vision with lower visual acuity).[1]

We determined the size for presenting our four stimulus types to be similar to those typically experienced by expert readers under real-life conditions. Thus, stimulus size and eccentricities were different between the four types of the stimuli. More specifically, for music notes, we measured the size of a crotchet found in Grieg's (1888) "Anitra's Dance" from *Peer Gynt Suite* No.1, Op.46 in *Piano Pieces the Whole World Plays* (i.e., a piano piece for postintermediate piano players). A music note (crotchet) with its corresponding five-line staff subtended a horizontal and vertical visual angle of 0.72° × 2.25° under a 40-cm

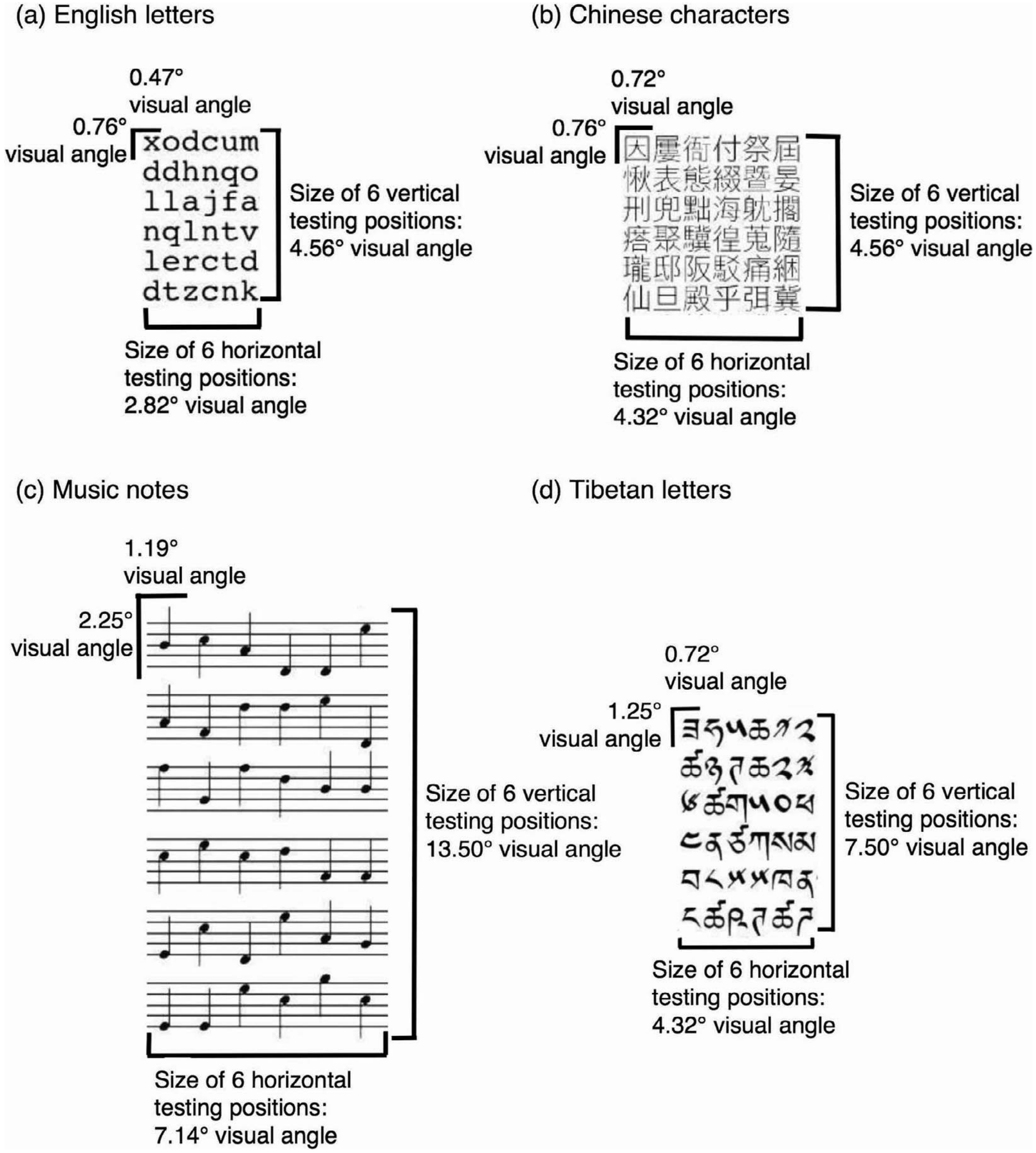


Figure 4. Stimulus displays for the four stimulus types: (a) English letters, (b) Chinese characters, (c) Music notes, and (d) Tibetan letters. These displays are scaled according to their relative sizes.

reading distance. Similarly, we measured the size of a lowercase English letter “x,” a Chinese character “因” and a Tibetan letter “ཟ” from English/Chinese/Tibetan newspapers, respectively. Lowercase English letter “x” and Tibetan letter “ཟ” were regarded as reference letters for measurement as they do not contain any ascenders or descenders (such as letter “h” and “g” in English and letter “ཀི” and “ད” in Tibetan). The Chinese character “因” was chosen due to its enclosed configuration. A lowercase English letter “x” subtended a horizontal and vertical visual angle of 0.29° × 0.29°, a Chinese character “因” of 0.43° × 0.43°, and a Tibetan letter “ཟ” of 0.43° × 0.72°, at a 40-cm reading distance. To ensure readability of the stimuli to both musicians and nonmusicians, we doubled the size of the stimuli in expert reading materials in the present study based on a pilot test with three participants.

Participants' viewing distance was fixed at 61 cm in our task. This viewing distance allowed us to setup an EyeLink 1000 eye tracker to ensure participants' central fixation. English letters were displayed in Courier—a serif font with fixed width, to ensure constant center-to-center spacing between letters.[2] The lowercase letter “x” subtended 0.47° of visual angle horizontally and 0.50° vertically on a rectangular background of 0.47° × 0.76°. The 6 × 6 testing positions of English letters thus subtended an overall visual angle of 2.82° × 4.56° (Figure 4a). Similarly, Chinese characters were presented in a serif font with fixed width, Microsoft DF-Hei, to ensure constant center-to-center spacing between characters. Each character

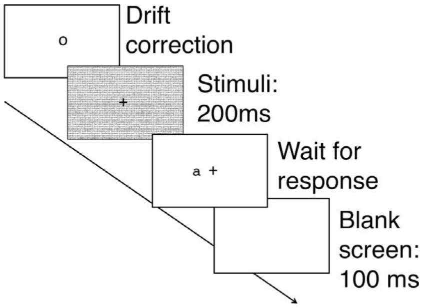


Figure 5. Procedure of the identity-matching task.

subtended a visual angle of 0.72° × 0.76°. With standard center-to-center character spacing, the 6 × 6 testing positions subtended an overall visual angle of 4.32° × 4.56° (Figure 4b). For music notes, a crotchet with its corresponding five-line staff subtended a visual angle of 1.19° × 2.25°, and the 6 × 6 testing positions subtended a visual angle of 7.14° × 13.50° (Figure 4c). Here we used a crotchet as a single unit comparable to that in the other stimulus types. As for Tibetan letters, the letter "ཟ" displayed in Himalaya font subtended a visual angle of 0.69° × 0.73° on a 0.72° × 1.25° rectangular background. Consequently, the 6 × 6 testing positions subtended an overall visual angle of 4.32° × 7.50° (Figure 4d).

The average luminance of stimuli was 3.6 cd/m^2. With 73.8 cd/m^2 background luminance, the Weber contrast of the stimuli was −0.95. Experiments were conducted using SR Experiment Builder with an EyeLink 1000 eye tracker (SR Research Ltd., Canada) to ensure participants' central fixation. A chinrest was used to reduce head movement. Calibration and validation were performed before the start of each block. Block order was counterbalanced, and trials were randomized across participants.

Procedure

Each trial started with a drift correction to ensure accurate central fixation. After detecting central fixation, a screen filled with stimuli was presented for 200 ms, which allowed only one fixation without eye movement in letter recognition (Legge et al., 2001). A probe stimulus was then presented at one of the 36 testing positions around the central fixation mark at the designated eccentricity level (Figure 3). The screen remained unchanged until participants responded, followed by a 100 ms blank screen (Figure 5). Participants had to judge whether the target stimulus was identical to the stimulus presented earlier at the same position on the screen filled with stimuli, as quickly and accurately as possible, without shifting their gaze away from the central fixation mark (+). Each position consisted of 10 "same" and 10 "different" trials that were randomly selected without repetitions. Note that this task required a yes/no response and thus the chance level was approximately at 50%. Participants responded by pressing buttons on a response box with both hands to avoid lateralization effects that may be induced by one-hand responses (Mohr, Pulvermüller, & Zaidel, 1994). Accuracies and RTs were recorded.

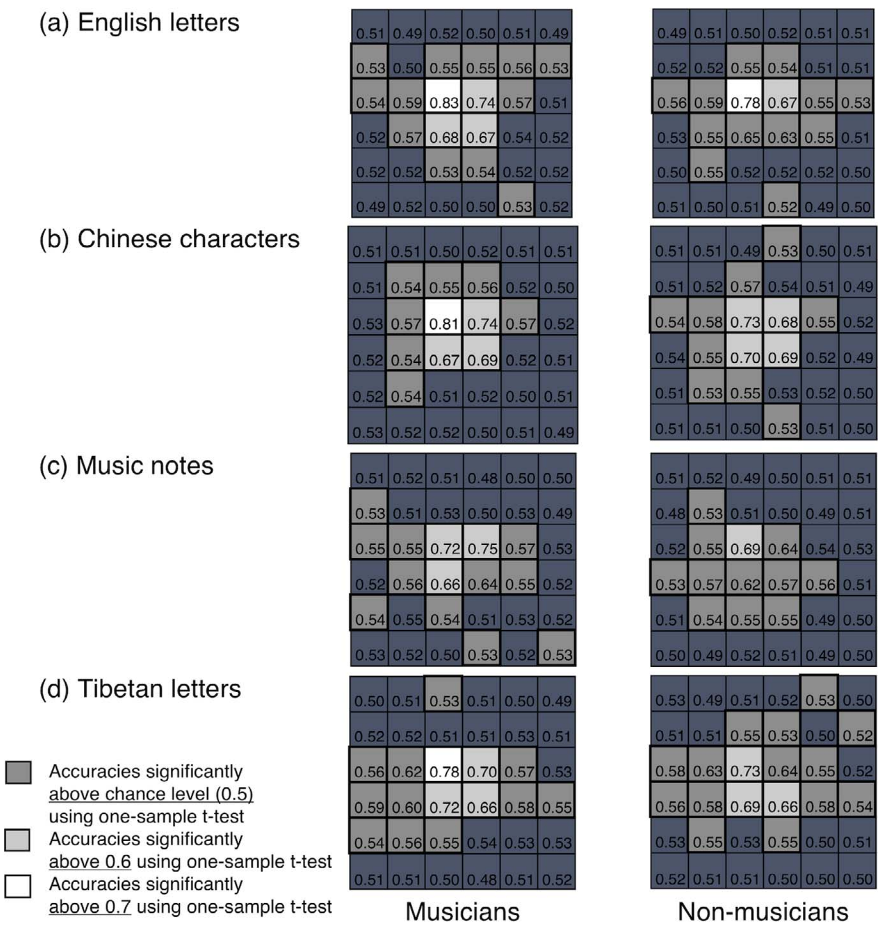
Prior to the identity-matching task, a demographic and music background questionnaire, the Lexical Test for Advanced Learners of English (LexTALE, Lemhöfer, & Broersma, 2012), the Edinburgh Handedness Inventory (Oldfield, 1971), the Freiburg Visual Acuity and Contrast Test (FrACT; Bach, 2006), and an N-back task (Lau et al., 2010) were conducted to assess participants' language and music learning background, handedness, visual acuity, and working memory capability, respectively. Musicians completed a piano note playing task in ScoreDate 3.2 (Callegari, 2015) to measure their music expertise and ensure their suitability to participate in our study.

Results

For visualization purposes, Figure 6 shows the average accuracy at each testing position in the musician and the nonmusician group, separately in the identity-matching task with English letters (Figure 6a), Chinese characters (Figure 6b), music notes (Figure 6c), and Tibetan letters (Figure 6d).

Visual spans in the identity matching task

We first compared the number of musicians and nonmusicians who achieved above-chance performance in different numbers of visual field regions in each eccentricity and horizontal visual field condition. For English letters, Table 1 below shows the results in the central RVF condition (i.e., the upper and lower visual fields in the central RVF, position 16 and 22 (in Figure 3). Thus, the number of visual field regions ranged from 0 to 2; see Figure 3). As can be seen in the table, there were more musicians with above-chance performance in both upper and lower visual field regions in the central RVF, whereas more nonmusicians achieved above-chance performance in only one of the two visual field regions or no region, $\chi^2(2) = 8.237$, $p = 0.016$, $V = 0.359$, i.e., a medium effect size. This result suggested that musicians had a larger visual span in the central RVF condition than nonmusicians. This effect was not observed in any of the other visual-field conditions, central LVF: $\chi^2(2) = 2.080$, $p = 0.353$; intermediate LVF: $\chi^2(2) = 0.292$, $p = 0.864$; intermedi-


(a) English letters

0.51	0.49	0.52	0.50	0.51	0.49	0.49	0.51	0.50	0.52	0.51	0.51
0.53	0.50	0.55	0.55	0.56	0.53	0.52	0.52	0.55	0.54	0.51	0.51
0.54	0.59	0.83	0.74	0.57	0.51	0.56	0.59	0.78	0.67	0.55	0.53
0.52	0.57	0.68	0.67	0.54	0.52	0.53	0.55	0.65	0.63	0.55	0.51
0.52	0.52	0.53	0.54	0.52	0.52	0.50	0.55	0.52	0.52	0.52	0.50
0.49	0.52	0.50	0.50	0.53	0.52	0.51	0.50	0.51	0.52	0.49	0.50

(b) Chinese characters

0.51	0.51	0.50	0.52	0.51	0.51	0.51	0.51	0.49	0.53	0.50	0.51
0.51	0.54	0.55	0.56	0.52	0.50	0.51	0.52	0.57	0.54	0.51	0.49
0.53	0.57	0.81	0.74	0.57	0.52	0.54	0.58	0.73	0.68	0.55	0.52
0.52	0.54	0.67	0.69	0.52	0.51	0.54	0.55	0.70	0.69	0.52	0.49
0.52	0.54	0.51	0.52	0.50	0.51	0.51	0.53	0.55	0.53	0.52	0.50
0.53	0.52	0.52	0.50	0.51	0.49	0.51	0.51	0.50	0.53	0.51	0.50

(c) Music notes

0.51	0.52	0.51	0.48	0.50	0.50	0.51	0.52	0.49	0.50	0.51	0.51
0.53	0.51	0.53	0.50	0.53	0.49	0.48	0.53	0.51	0.50	0.49	0.51
0.55	0.55	0.72	0.75	0.57	0.53	0.52	0.55	0.69	0.64	0.54	0.53
0.52	0.56	0.66	0.64	0.55	0.52	0.53	0.57	0.62	0.57	0.56	0.51
0.54	0.55	0.54	0.51	0.53	0.52	0.51	0.54	0.55	0.55	0.49	0.50
0.53	0.52	0.50	0.53	0.52	0.53	0.50	0.49	0.52	0.51	0.49	0.50

(d) Tibetan letters

0.50	0.51	0.53	0.51	0.50	0.49	0.53	0.49	0.51	0.52	0.53	0.50
0.52	0.52	0.51	0.51	0.53	0.51	0.51	0.51	0.55	0.53	0.50	0.52
0.56	0.62	0.78	0.70	0.57	0.53	0.58	0.63	0.73	0.64	0.55	0.52
0.59	0.60	0.72	0.66	0.58	0.55	0.56	0.58	0.69	0.66	0.58	0.54
0.54	0.56	0.55	0.54	0.53	0.53	0.53	0.55	0.53	0.55	0.50	0.51
0.51	0.51	0.50	0.48	0.51	0.52	0.52	0.51	0.51	0.50	0.50	0.50

Figure 6. The average accuracies of musicians (left) and nonmusicians (right) in the identity-matching task with (a) English letters, (b) Chinese characters, (c) music notes, and (d) Tibetan letters. Regions with different levels of accuracy (according to one-sample *t* tests) are marked with different shades of gray. Note that missing data due to below-chance accuracy at the previous eccentricity level were replaced with chance level performance of 0.5.

ate RVF: $\chi^2(2) = 5.563$, $p = 0.062$; peripheral LVF: $\chi^2(2) = 2.538$, $p = 0.281$; or peripheral RVF: $\chi^2(2) = 0.652$, $p = 0.722$.

For Chinese characters, musicians and nonmusicians did not differ significantly in achieving above-chance performance in any eccentricity and visual-field condition, central LVF: $\chi^2(2) = 2.012$, $p = 0.366$; central RVF: $\chi^2(2) = 2.089$, $p = 0.352$; intermediate LVF: $\chi^2(2) = 0.567$, $p = 0.753$; intermediate RVF: $\chi^2(2) = 0.680$, $p = 0.712$; or peripheral RVF: $\chi^2(2) = 0.525$, $p = 0.769$), except for the peripheral LVF: $\chi^2(2) = 16.584$, $p < 0.001$, $V = 0.509$, i.e., a large effect size. As shown in Table 2, more musicians had above-chance performance in 1 out of 2 visual field regions, whereas more

	Number of visual field regions with above-chance performance in the central RVF for English letters		
Number of visual field regions (upper and lower visual fields)	0	1	2
Number of musicians ($n = 32$)	2	4	26
Adjusted standardized residual	−1.2	−2.3*	2.9**
Number of nonmusicians ($n = 32$)	5	12	15
Adjusted standardized residual	1.2	2.3*	−2.9**

Table 1. The number of musicians and nonmusicians with above-chance performance in the central RVF condition for English letters. *Notes*: Adjusted standard residual provides a test for the significance of individual cells contributing to a significant chi-square test result. *Adjusted standardized residuals can be interpreted approximately as z score ±1.96, $p = 0.002$; **adjusted standardized residuals can be interpreted approximately as z score ±2.58, $p < 0.001$.

	Number of visual field regions with above-chance performance in the peripheral LVF for Chinese characters		
Number of visual field regions (upper and lower visual fields)	0	1	2
Number of musicians ($n = 32$)	7	21	4
Adjusted standardized residual	−2.6**	4.1***	−1.8
Number of nonmusicians ($n = 32$)	17	5	10
Adjusted standardized residual	2.6**	−4.1***	1.8

Table 2. The number of musicians and nonmusicians with above-chance performance in the peripheral LVF condition for Chinese characters. *Notes*: **Adjusted standardized residuals can be interpreted approximately as z score: ±2.58, $p = 0.009$; ***adjusted standardized residuals can be interpreted approximately as z score: ±3.29, $p < 0.001$.

nonmusicians had above-chance performance in either no region or 2 out of 2 visual field regions. Thus, even though in the chi-square test there is a large difference of visual span between musicians and nonmusicians in the peripheral LVF, the bimodal performance level for the nonmusicians in Table 2 renders a general statement about which group is better inconclusive.

Similarly, for music notes, no significant difference was found between musicians and nonmusicians in achieving above-chance performance in any eccentricity and visual-field condition, central LVF: $\chi^2(2) = 4.609$, $p = 0.100$; central RVF: $\chi^2(2) = 2.327$, $p = 0.312$; intermediate LVF: $\chi^2(2) = 0.083$, $p = 0.959$; intermediate RVF: $\chi^2(2) = 1.077$, $p = 0.584$; peripheral RVF: $\chi^2(2) = 1.271$, $p = 0.530$, except for the peripheral LVF: $\chi^2(2) = 7.634$, $p = 0.022$, $V = 0.345$, i.e., a medium effect size. As shown in Table 3, more musicians had above-chance performance in 1 out of 2 visual field regions, whereas more nonmusicians had above-chance performance in either no visual field region or 2 out of 2 visual field regions. This result did not indicate whether musicians and non-musicians differed in visual span in the periphery LVF condition.

For Tibetan letters, musicians and nonmusicians did not differ significantly in achieving above-chance performance in any eccentricity and visual-field condition, central LVF: $\chi^2(2) = 2.796$, $p = 0.247$; central RVF: $\chi^2(2) = 1.726$, $p = 0.422$; intermediate LVF: $\chi^2(2) = 2.090$, $p = 0.352$; intermediate RVF: $\chi^2(2) = 2.119$, $p = 0.347$; peripheral LVF: $\chi^2(2) = 0.104$, $p = 0.949$; peripheral RVF: $\chi^2(2) = 0.366$, $p = 0.833$.

In summary for the visual span results, more musicians obtained above-chance performance in both upper and lower visual fields in the central RVF condition as compared with nonmusicians when matching English letters, suggesting that they had a larger visual span in the central RVF. This effect was not observed in any other condition in English letter matching, or any condition in matching Chinese characters, music notes, or Tibetan letters.

Participants' accuracies and RTs in the identity-matching task

Mixed ANCOVA was used to examine participants' identification accuracies and RTs in the identity-matching task. Two within-subject variables—Eccentricity (center vs. intermediate vs. periphery) and horizontal visual field (LVF vs. RVF)—and a between-subject variable—group (musicians vs. nonmusicians)—were included in the analysis. Since musicians outperformed nonmusicians in English and Chinese proficiency, participants' English and Chinese proficiency were included as covariates to control these possible confounding variables. In our analysis, we substituted the missing data (i.e., participants who did not reach a testing position due to below chance-level (0.5) accuracy in an adjacent position at the previous eccentricity level) with chance-level performance (0.5).

	Number of visual field regions with above-chance performance in the peripheral LVF for music notes		
Number of visual field regions (upper and lower visual fields)	0	1	2
Number of musicians ($n = 32$)	8	21	3
Adjusted standardized residual	−1.8	2.8**	−1.4
Number of nonmusicians ($n = 32$)	15	10	7
Adjusted standardized residual	1.8	−2.8**	1.4

Table 3. The number of musicians and nonmusicians with above-chance performance in the peripheral LVF condition for music notes. *Notes*: **Adjusted standardized residuals can be interpreted approximately as z score: ±2.58, $p = 0.005$.

	Main effects							Interactions					
	Eccentricity			Horizontal visual field		Group		Horizontal visual field × group			Eccentricity × horizontal visual field × group		
	F	p	η_p^2	F	p	F	p	F	p	η_p^2	F	p	η_p^2
English letters	(1.161, 66.197) = 11.373	0.001	0.166	(1, 57) = 0.126	0.724	(1, 57) = 1.822	0.182	(1, 57) = 1.362	0.248		(2, 56) = 0.386	0.603	
Chinese characters	(1.326, 75.598) = 6.865	0.006	0.107	(1, 57) = 1.392	0.243	(1, 57) = 0.583	0.448	(1, 57) = 1.315	0.256		(2, 56) = 0.328	0.657	
Music notes	(1.222, 69.644) = 2.303	0.128		(1, 57) = 0.057	0.811	(1, 57) = 2.863	0.096	(1, 57) = 3.996	0.050	0.066	(2, 56) = 4.375	0.031	0.071
Tibetan letters	(1.293, 73.700) = 6.961	0.006	0.109	(1, 57) = 0.665	0.418	(1, 57) = 1.025	0.316	(1, 57) = 0.161	0.689		(2, 56) = 0.132	0.804	

Table 4. Statistical results of the accuracies in the identity-matching task.

Accuracies in the identity-matching task

For matching-accuracy with English letters, a significant main effect of eccentricity was observed, $F(1.161, 66.197) = 11.373$, $p = 0.001$, $\eta_p^2 = 0.166$, i.e., a large effect size: Participants performed best when matching English letters presented at the center (70.7%), followed by the intermediate (54.2%), and the periphery condition (51.3%). No other significant effect was found (Table 4), suggesting that musicians and nonmusicians performed similarly in English letter matching accuracy.

For Chinese characters, there was again a significant main effect of eccentricity with a medium effect size, $F(1.326, 75.598) = 6.865$, $p = 0.006$, $\eta_p^2 = 0.107$: Participants had the best performance when Chinese characters were presented at the center (71.3%), followed by those presented at the intermediate (53.7%) and the periphery condition (51.2%). No other significant effect was found (Table 4). These results suggested that musicians and nonmusicians had similar performance in matching Chinese characters.

For music notes, there was a significant interaction between horizontal visual field and group, $F(1, 57) = 3.996$, $p = 0.050$, $\eta_p^2 = 0.066$, i.e., a medium effect size. This effect interacted with eccentricity: There was a significant three-way interaction between eccentricity, horizontal visual field, and group, $F(2, 56) = 4.375$, $p = 0.031$, $\eta_p^2 = 0.071$, i.e., a medium effect size. When we examined the data in different eccentricity conditions separately, a significant interaction of horizontal visual field and group was observed at the center, $F(1, 57) = 5.467$, $p = 0.023$, $\eta_p^2 = 0.088$, i.e., a medium effect size, but not in the intermediate, $F(1, 57) = 0.637$, $p = 0.428$, or the periphery, $F(1, 57) = 0.679$, $p = 0.413$, conditions. When we further examined the data in the central RVF and central LVF conditions separately, the accuracy difference between musicians and nonmusicians was significant in the central RVF, $F(1, 57) = 7.524$, $p = 0.008$, $\eta_p^2 = 0.117$, i.e., a medium effect size; M = 70.3%; NM = 60.0%; but not in the central LVF, $F(1, 57) = 0.503$, $p = 0.481$; M = 68.3%; NM = 65.7%; see Figure 7. No other significant effect was observed (Table 4).

For Tibetan letters, a significant main effect of eccentricity with a medium effect size was observed, $F(1.293, 73.700) = 6.961$, $p = 0.006$, $\eta_p^2 = 0.109$: Participants performed the best when Tibetan letters were presented at the center (69.8%), followed by the intermediate (54.8%), and periphery conditions (52.0%). No other significant effect was found (Table 4). This result suggested that musicians and nonmusicians performed similarly in Tibetan letter matching accuracy.

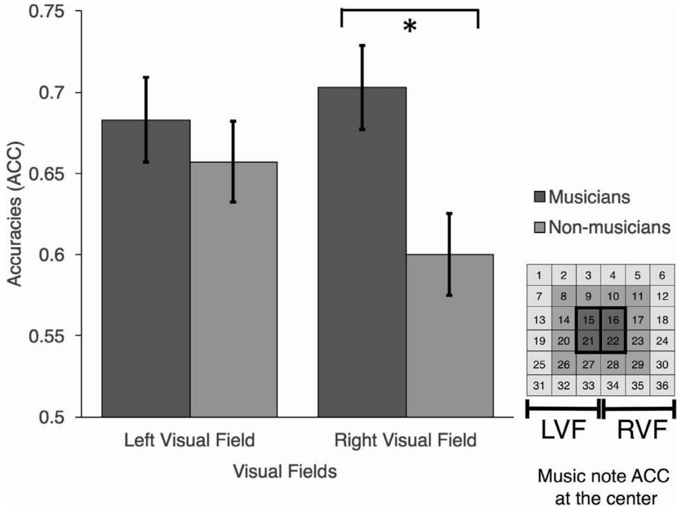


Figure 7. Mean accuracies at the LVF and RVF positions in the center condition (as shown by the inset on the right) in the identity-matching task with music notes. (Error bars: ±1 *SE*, *$p = 0.023$).

RTs in the identity-matching task

No significant effect was observed in the RT for identifying English letters, Chinese characters, music notes, or Tibetan letters (Table 5). This result suggested that musicians and nonmusicians performed similarly in the identity-matching RT of all four stimulus types.

Discussion

Here we examined how music-reading expertise influences the visual span for music notes, English letters, Chinese characters, and novel symbols (i.e., Tibetan letters) by an identity-matching task. Music and English reading both involve left-to-right sequential symbol processing and decomposition of visual stimuli into components for sound mapping, which have been shown to induce RVF/LH processing advantages (Hsiao & Lam, 2013; Segalowitz et al., 1979). Accordingly, we hypothesized that musicians who are also expert English readers may have an advantage over nonmusician expert English readers in the RVF in English-letter matching. In contrast to music and English reading, Chinese characters can be read in all directions, and components of Chinese characters are not always arranged in a left-right structure within a character. In addition, as a logographic language, Chinese reading does not involve grapheme-phoneme correspondence, and thus has been shown to involve more bilateral or right-lateralized visual processing as compared with English reading (Tan et al., 2001; Tzeng et al., 1979). Therefore, we

	Main effects						Interactions			
	Eccentricity		Horizontal visual field		Group		Horizontal visual field × group		Eccentricity × horizontal visual field × group	
	F	*p*	*F*	*p*	*F*	*p*	*F*	*p*	*F*	*p*
English letters	(1.685, 75.806) = 0.021	0.965	(1, 45) = 0.859	0.359	(1, 45) = 0.086	0.770	(1, 45) = 0.785	0.380	(2, 44) = 2.369	0.121
Chinese characters	(1.491, 70.090) = 0.022	0.949	(1, 47) = 0.529	0.471	(1, 47) = 0.796	0.377	(1, 47) = 0.216	0.644	(2, 46) = 0.013	0.984
Music notes	(1.616, 66.274) = 2.812	0.078	(1, 41) = 1.847	0.182	(1, 41) = 2.613	0.114	(1, 41) = 0.897	0.349	(2, 40) = 0.033	0.964
Tibetan letters	(1.630, 74.985) = 0.965	0.370	(1, 46) = 0.626	0.433	(1, 46) = 0.837	0.365	(1, 46) = 2.286	0.137	(2, 45) = 0.082	0.914

Table 5. Statistical results of the RTs in the identity-matching task.

hypothesized that musicians and nonmusicians may not differ in the visual span for Chinese characters.

Consistent with our hypothesis, our results showed that more musicians were able to identify English letters with above-chance performance in both upper and lower visual fields in the central RVF condition as compared with nonmusicians. This finding suggests that music-reading expertise may modulate the visual span in English reading due to similarities in the respective perceptual processes involved. This is in line with findings that the left-to-right sequential symbol processing involved in both music notation and English word reading made music notes and English letters recognized in the RVF more often than in the LVF (Brysbaert & Nazir, 2005; Wong & Hsiao, 2012). With extensive left-to-right music-reading experience, musicians developed a processing advantage for music notes in the RVF/LH through perceptual learning (Wong & Hsiao, 2012), and this effect may be transferred to stimuli with similar processing requirements such as English letters. In addition, both the note-to-sound mapping in music-notation reading and the grapheme-phoneme correspondence in English letter reading (e.g., Brown et al., 2006) may involve more LH analytic processing than RH processing (Bradshaw & Nettleton, 1981; Hébert & Cuddy, 2006; Hsiao & Lam, 2013; Segalowitz et al., 1979), which may benefit similar analytic processing in the RVF in general. These similarities between music and English reading may account for the processing advantage for English letter identification in musicians as compared with nonmusicians.

For identity matching with Chinese characters, consistent with our hypothesis, musicians and nonmusicians did not differ in their performance in matching Chinese characters, suggesting that music-reading expertise has less influence on the visual span for Chinese characters than for English letters. In contrast to the left-to-right sequential symbol processing required in music reading, components in a Chinese character can be arranged in different configurations, including left-right, top-bottom, concentric, upper-right and below, upper-left and below, partially-enclosed, lower-left and above, etc. (see Figure 1). In addition, Chinese can be read in all directions (left to right, right to left, or vertically). Consequently, the perceptual processes involved in Chinese character reading may be fundamentally different from those in music-notation reading. Also, Chinese reading does not involve grapheme-phoneme correspondence, and thus decomposition of a character into its components is not required in reading. This has been suggested to account for the more right-lateralized (Tzeng et al., 1979) or bilateral (Tan et al., 2001) orthographic/visual processing involved in Chinese character recognition in contrast to a RVF/LH advantage typically observed in music-note or English word recognition (Brysbaert & d'Ydewalle, 1990; Brysbaert & Nazir, 2005; Segalowitz et al., 1979; Wong & Hsiao, 2012). Thus, the dissimilarities in perceptual processes between music and Chinese reading may explain the limited facilitation effect of music-reading expertise on the visual span for Chinese characters. Taken together, our results of English letter and Chinese character identification suggest that the modulation of music-reading experience on the visual span for stimulus identification depends on the similarities in the perceptual processes involved. They also suggest that visual span is not just an area within which participants can extract information regardless of stimulus type. Thus, visual span is stimulus specific, and can be modulated by experience with other stimulus types that involve similar perceptual processes.

For identity matching with music notes, musicians had better matching accuracy than nonmusicians in the center-RVF condition, consistent with previous studies showing an RVF advantage in music-notation reading (Segalowitz et al., 1979; Wong & Hsiao, 2012). This finding was also consistent with the results of identity-matching with English letters in the current study, suggesting that musicians' advantage over nonmusicians in identity matching with English letters in the center-RVF may be related to their music-reading experience. This RVF advantage in musicians may be the result of perceptual learning due to the left-to-right reading direction in music-notation reading, and thus music notations are typically recognized in the RVF more often than the LVF. In particular, since temporal information (i.e., time) is important for music reading and playing, musicians typically read further ahead to the right to ensure playing in time (Goolsby, 1994). Consistent with this speculation, Wong and Hsiao (2012) showed that highly skilled musicians had the best identification performance of musical segments when their initial fixation was directed towards the beginning of a musical segment (i.e., a left-biased optimal viewing position, or OVP; O'Regan, Lévy-Schoen, Pynte, & Brugaillère, 1984) with most of the segment projected to their RVF. This phenomenon was not observed in nonmusicians. This left-biased OVP effect may have been gradually developed as a result of perceptual learning through extensive left-to-right music-reading practice. It may also be related to the finding that musical segment beginnings are more informative for identification than segment endings, similar to English words (Chan & Hsiao, 2016), and thus attract more eye fixations during reading. Consequently, musical segments were recognized more often in the RVF, leading to the RVF advantage observed in our music-note identification task. In addition to the influence from reading direction, music-notation reading involves note-to-sound mapping, and this kind of analytic encoding process was suggested to involve LH lateralization (Hébert & Cuddy, 2006; Segalowitz et al., 1979). This effect may also account for the RVF advantage in music-note identification accuracy observed in the current study.

Although musicians had higher music-note identification accuracy than nonmusicians in the center-RVF condition, there were comparable numbers of musicians and nonmusicians with above-chance music-note matching performance in the center-RVF condition. This result showed that musicians did not have a larger visual span for music notes, inconsistent with our hypothesis. We speculated that this phenomenon might be related to the configuration of the music-note stimuli used. For example, Reingold et al. (2001) emphasized the importance of stimulus meaningfulness on the size of chess experts' visual span. More specifically, chess experts only showed a larger visual span for meaningfully structured chess configurations but not for random chess patterns. Similarly, the configuration of the music-note stimuli used here may not appear familiar or meaningful to musicians, since music notes are usually shown in groups with clearly defined clef, time signature, key signature (if any), and motif/phrase structure in music notations and rarely in isolation in a random order without any rhythmic patterns and vertical bar lines as shown in the present study. Future work will examine this possibility.

For novel symbols (i.e., Tibetan letters), we did not find evidence showing significant differences between musicians and nonmusicians in their identity-matching performance. Previous research has suggested that musicians may have better local visual processing abilities than non-musicians (e.g., Stoesz, Jakobson, Kilgour & Lewycky, 2007) as a result of their extensive music training. For example, Stoesz et al., (2007) showed that musicians outperformed nonmusicians in the Group Embedded Figures Test (GEFT; Witkin, Oltman, Raskin, & Karp, 1971), in which they were asked to search for one of nine simple geometric embedded figures from a series of 25 complex figures. More musicians (86.4%) were classified as individuals with local processing bias than nonmusicians (53.8%) in this GEFT task according to the cut-off accuracy score defined by Ellis (1996). In another experiment reported in Stoesz et al. (2007), musicians performed significantly better than nonmusicians in a block design subtest from the Wechsler Adult Intelligence Scale (WAIS III; Wechsler, Coalson & Raiford, 1997), in which participants were asked to replicate a geometric pattern (i.e., global information) using the top surfaces of colored blocks (i.e., local information). Similarly, in a possible/impossible figure copy task, musicians outperformed nonmusicians in copying impossible figures (i.e., blocks that were unreasonably jointed), whereas both groups had similar performance in copying possible block drawings. Since the identification of physical plausibility of a block figure relies on its global information, musicians' superiority in copying impossible figures suggested that they might attend more to local features and were less affected by physically implausible global configurations in the task. While these results suggest that musicians may have enhanced domain-general local visual attention ability, this ability may not be readily transferrable to their visual span for identifying novel symbols.

Note that in the present study, the visual span was studied in a distributed attention condition, in which participants were required to pay attention to the whole stimulus without orienting their attention to a specific location beforehand. Or more specifically, it was assessed as identification performance when the target location within the stimulus was unknown. In contrast, in some previous visual span studies, participants were provided with a cue prior to the stimulus presentation to orient their attention to the target location in advance (e.g., Legge et al., 2001). Future work will examine whether we can observe similar modulation effects when using a different method for assessing visual span. Future work will also examine whether musicians' larger visual span for English letters and novel symbols will result in a higher reading speed using the RSVP approach (Chung et al., 2004; Legge et al., 2007; Yu et al., 2010) or in natural reading conditions.

Conclusion

In conclusion, here we showed that musicians had a better performance in English letter identification in the RVF as compared with nonmusicians. This effect may be due to the left-to-right sequential symbol processing and the LH advantage in analytic perceptual processes involved in both music and English reading. In contrast, this modulation effect was not observed in the visual span for Chinese character identification. This phenomenon may be due to the dissimilarities in stimulus configuration, reading direction, and the requirement of analytic stimulus processing between music and Chinese reading. Taken together, these results suggest that the modulation of music-reading expertise on the visual span for stimulus identification depends on the similarities in the perceptual processes involved.

Keywords: Music-reading expertise, *visual span*, *English letter identification*, *Chinese character identification*, *novel symbol identification*

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Commercial relationships: none.
Corresponding author: Janet H. Hsiao.
Email: jhsiao@hku.hk.
Address: Department of Psychology, University of Hong Kong, Hong Kong, SAR.

Footnotes

[1] Another reason for adopting the progressive testing design was that it significantly reduced the amount of time required for the procedure. With the current design, each participant already required about 3 to 4 hours to finish. Note, however, that this design could influence the testing power due to missing data.

[2] Note, however, that Courier is a relatively outdated font, and thus participants may not have much reading experience with it.

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