Congenital blindness enhances perception of musical rhythm more than melody in Mandarin speakers

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Abstract: This study adopted the Musical Ear Test [Wallentin, Nielsen, Friis-Olivarius, Vuust, and Vuust (2010). Learn. Indiv. Diff. **20**, 188–196] to compare musical competence of sighted and congenitally blind Mandarin speakers. On the rhythm subtest, the blind participants outperformed the sighted. On the melody subtest, however, the two groups performed equally well. Compared with sighted speakers of non-tonal languages reported in previous studies [Wallentin, Nielsen, Friis-Olivarius, Vuust, and Vuust (2010). Learn. Indiv. Diff. **20**, 188–196; Bhatara, Yeung, and Nazzi (2015). J. Exp. Psychol. Hum. Percept. Perform. **41**(2), 277–282], sighted Mandarin speakers performed better only on the melody subtest. These results indicate that tonal language experience and congenital blindness exert differential influences on musical aptitudes with rhythm perception reflecting a cross-modal compensation effect and melody perception dominated by a cross-domain language-to-music transfer effect.

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1. Introduction

Being deprived of visual sensation, congenitally blind people may harness other intact sensory gateways more effectively as a means of cognitive compensation (Kupers *et al.*, 2011; Hötting and Röder, 2009). The auditory channel has been frequently studied with a number of publications reporting better-than-normal results in early-blind individuals using a variety of tasks, which included pitch discrimination (Arnaud *et al.*, 2018), beat asynchrony detection (Lerens *et al.*, 2014), voice recognition (Bull *et al.*, 1983), spatial localization (Gougoux *et al.*, 2005; Lessard *et al.*, 1998), verbal memory (Amedi *et al.*, 2003), and identification of speech sounds (Hughdahl *et al.*, 2004). Despite the cumulative evidence in support of altered organization and compensatory enhancement of the spared senses, there are also some inconsistent findings in the literature that require a systematic approach toward understanding the multisensory experiential changes that mediate cross-modal plasticity in blind individuals (Bavelier and Neville, 2002). For instance, Zwiers *et al.* (2001) found that when the target sound was presented with a noisy background, sighted subjects were better at locating the target than blind subjects. They argued that compensatory mechanisms involving other senses cannot replace the role of visual feedback for the full development of the ability to locate sounds in complex environments. In this view, early blindness may also lead to deficient development of multisensory perceptual and cognitive systems.

Comparative tests of musical aptitudes have produced mixed results. In one study, early-blind individuals demonstrated superior performance to sighted people in

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discriminating transported melodies but not simple melodies (Voss and Zatorre, 2012). In another study (Carrara-Augustenborg and Schultz, 2017), although the blind group showed an advantage for learning non-metrical auditory rhythms, they appeared to learn metrical rhythms less readily than the sighted individuals. It is noteworthy to point out that both the blind and sighted individuals in the Voss and Zattore (2012) study had several years of formal musical training. Whether blind and sighted people without formal musical training would differ in simple melody and rhythm discrimination needs to be further investigated.

Apart from musical training, native language experience has been shown to have profound influences on the listening brain, which is attributed to the bi-directional association between speech and music [Wong *et al.*, 2012; Deutsch *et al.*, 2006; Chen *et al.*, 2016; see Asaridou and McQueen (2013) for a review]. For example, native speakers of a tonal language (e.g., Mandarin Chinese) have better musical pitch perception and showed far greater prevalence of absolute pitch than speakers of a non-tonal language (e.g., English, Dutch, French) (Deutsch *et al.*, 2006; Wong *et al.*, 2012; Chen *et al.*, 2016). In music composition, the prosodic features (e.g., speech rhythm and pitch patterns) of a composer's native language have been found to affect the rhythmic and melodic properties of their music (Patel and Daniele, 2003; Patel *et al.*, 2006). It remains unclear, however, how native language experience with a tonal language affects music perception in blind people. As the previous studies tested melody (Voss and Zatorre, 2012) and rhythm separately (Carrara-Augustenborg and Schultz, 2017) without taking into account the tonal language experience, further research in the tonal-language-speaking population is needed to gain insights about the perceptual gains and losses associated with congenital blindness.

In the present study, we recruited Mandarin speakers without formal music training and adopted the Musical Ear Test (MET) (Wallentin *et al.*, 2010) to measure both melody and rhythm discrimination abilities of congenitally blind people in comparison with their sighted counterparts. Considering the superior performance of sighted Mandarin speakers on musical melody perception over rhythm perception (Wong *et al.*, 2012), we were interested in examining how native tonal language experience affects music perception in congenitally blind Mandarin speakers. In particular, we aimed to determine whether tonal language experience works in concert with congenital blindness to enhance the discrimination of music melody and rhythm as a whole or not.

2. Methods

2.1 Subjects

Twenty-eight sighted (10 females; age range: 18–27 years) and 18 congenitally blind (5 females; age range: 20–30 years) participants with no formal musical training took part in our study. All participants were native speakers of Mandarin Chinese and were undergraduate or postgraduate students from several universities in Beijing. They all passed a hearing screening at 25 dB hearing level for octave frequencies between 125 and 4000 Hz. There were no significant between-group differences in the hearing thresholds at any frequencies. In each case of blindness, the visual deficit resulted from anomalies in peripheral structures and led to total blindness except for minimal residual light sensitivity in eight participants. None of the sighted or blind participants had a history of neurological, psychiatric, or neuropsychological problems. Written informed consent was obtained from each participant. The study was approved by the Institutional Review Board of the National Key Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University.

2.2 Musical aptitude measurement

Musical aptitude was measured by using MET, a standardized test of music perception developed by Wallentin *et al.* (2010), which focuses on the two fundamental aspects of music, i.e., melody and rhythm with either subtest consisting of 52 trials (pairs of melodic/rhythmic phrases) (Fig. 1). Each melodic phrase is played with sampled piano sounds containing three to eight notes, and each rhythmic phrase is played with wood block sounds containing 4 to 11 beats. All phrases have a duration of one measure and are presented at a rate of 100 beats per minute.

Participants were tested individually in a quiet room with ambient noise level below 45 dB(A). The stimuli were presented via headphones at 70 dB sound pressure level with equal phase and intensity at both ears. Participants judged and reported verbally whether the two phrases in a trial were identical. An experimenter recorded each response on the answer sheet. Phrases within a trial were separated by three beats (or

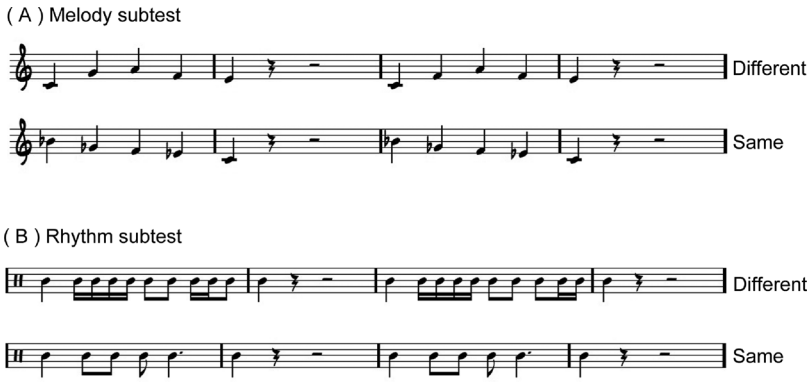

Fig. 1. Example trials from the MET. A pair of musical phrases with same or different melodic/rhythmic patterns are presented in (A) and (B), respectively.

about 1.8 s), and participants had to respond within the time limit. The presentation order of the rhythm and melody subtests was counterbalanced across participants. Before each subtest participants were given two example trials with feedback. However, no feedback was given during the test itself.

3. Results

A 2×2 repeated measures analysis of variance (ANOVA) was carried out with musical aspect (melody vs rhythm) as the within-subject factor and participant group (sighted vs blind) as the between-subject factor. There was a significant main effect of participant group [$F(1, 44) = 4.588$, $p = 0.038$, partial $\eta^2 = 0.094$], indicating that the blind individuals have higher musical aptitudes than their sighted peers. However, the main effect of musical aspect was not significant [$F(1, 44) = 1.492$, $p = 0.228$, partial $\eta^2 = 0.033$], indicating that rhythmic and melodic patterns were discriminated with similar accuracies.

ANOVA tests also revealed significant interaction effects between participant group and musical aspect [$F(1, 44) = 8.783$, $p = 0.005$, partial $\eta^2 = 0.166$], indicating that discrimination accuracies of rhythmic and melodic patterns disproportionately increased in the blind compared with the sighted participants. Further simple effect analyses revealed that the blind participants outperformed their sighted counterparts on the discrimination of rhythmic patterns [$F(1, 44) = 10.349$, $p = 0.002$, partial $\eta^2 = 0.190$], but the two groups performed similarly on the discrimination of melodic patterns [$F(1, 44) = 0.215$, $p = 0.645$, partial $\eta^2 = 0.005$]. Furthermore, melodic patterns were better discriminated than rhythmic patterns by the sighted participants [$F(1, 44) = 11.190$, $p = 0.002$, partial $\eta^2 = 0.203$], but the two musical aspects were discriminated with similar accuracies by the blind individuals [$F(1, 44) = 1.247$, $p = 0.270$, partial $\eta^2 = 0.028$].

4. Discussion

The present study examined the two fundamental aspects of musical aptitude, i.e., melody and rhythm abilities of native Mandarin speakers with congenital blindness compared to sighted counterparts (Fig. 2). The significant main effect of the group demonstrated that blind individuals had higher general musical aptitudes than sighted peers. However, the significant interaction between participant group and musical aspect further revealed that the superiority of blind people in music perception is confined to rhythm only.

The association between speech and music processing has been explored by many previous studies and a growing body of research suggests a bidirectional relationship between the two domains (Asaridou and McQueen, 2013). On the one hand, people with formal musical training have superior abilities in the perception and neural encoding of native and foreign speech sounds (Wong *et al.*, 2007; Patel, 2011; Wu *et al.*, 2015). On the other hand, experience in speaking different languages affect processing of different musical properties at various levels (Wong *et al.*, 2012; Patel and Daniele, 2003; Deutsch *et al.*, 2006). In order to further examine the effect of native language experience on music perception, we attempted one-sample *t*-tests to compare the performances of sighted Mandarin speakers in our study with their non-tonal language counterparts reported in previous studies (i.e., sighted Danish and French speakers in Wallentin *et al.*, 2010 and Bhatara *et al.*, 2015, respectively). Sighted Mandarin speakers performed significantly better than Danish speakers [$t(27) = 5.113$, $p < 0.001$] and French speakers [$t(27) = 4.715$, $p < 0.001$] only on the melody subtest. There were

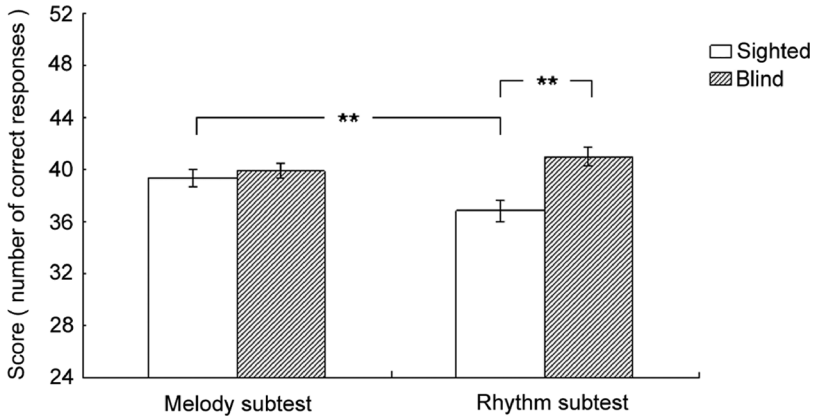

Fig. 2. Scores of the melody and rhythm subtests for the sighted and congenitally blind groups. **significant at $p < 0.01$. Error bars represent standard deviation across subjects.

no significant differences on the rhythm subset [$t(27) = 0.094$, $p = 0.925$ for the Chinese vs Danish comparison; $t(27) = -0.305$, $p = 0.763$ for the Chinese vs French comparison]. A cautionary note is necessary here as these data across studies were not collected by the same researchers in the same lab. Nonetheless, these results consistently point to the influence of tonal language experience on musical pitch processing. In a tone language like Mandarin Chinese, pitch is used to distinguish lexical meaning in addition to intonation, whereas in non-tonal languages like Danish and French, pitch is mainly employed as a prosodic feature to signal intonation. Our results are consistent with previous literature, suggesting that native tonal language experience can improve pitch perception in general. The enhanced ability transfers to musical pitch processing, reflecting the significant cross-domain effect in pitch perception. It is worth noting, however, that sighted Mandarin, French, and Danish speakers showed no differences in rhythm discrimination although their native languages show distinct rhythmic characteristics. In phonological theories, languages are ordered into three rhythmic classes, namely, stress-timed, syllable-timed, and mora-timed. While Danish is classified as a stress-timed language, French and Mandarin are typical syllable-timed languages (Ramus *et al.*, 1999; Goswami *et al.*, 2011). Although the rhythmic characteristics of composers' native language affect the rhythmic properties of their music (Patel and Daniele, 2003), there is no evidence that this cross-domain transfer effect exists in rhythmic perception. For example, Wong *et al.* (2012) used the online version of Montreal Battery of Evaluation of Amusia to examine musical melody and rhythm perception by native Canadian French, Canadian English, and Cantonese speakers, and found no group differences in rhythm perception. These results seem to imply that rhythmic perception is more fundamentally rooted than melodic perception, which could be a consequence of more shared similarities in musical timing patterns across cultures or inherently how the neural system is tuned in evolution to show synchronized responses to timing information. Because only a very limited number of languages have been examined in existing studies, more language samples need to be included to further verify whether there is cross-domain association in speech and music rhythm perception.

A number of previous studies have investigated pitch perception by blind individuals and reported superiority of pitch discrimination by blind over sighted people (Gougoux *et al.*, 2004; Wan *et al.*, 2010). At first sight, our finding that blind and sighted individuals performed similarly on melody discrimination appears contradictory to the results of these previous studies. Our result, however, is consistent with that of Voss and Zatorre (2012), which showed that blind and sighted groups with years of formal musical training discriminated simple music melody equally well. This discrepancy between the significant results and the null findings might be partly due to the experiential factor of tonal language experience (which can lead to similar results as musical training) and partly due to the fact that different stimulus types were used in the studies. While the studies that reported significant pitch perception results used pairs of pure tones lasting hundreds of milliseconds, the studies with null results on melody discrimination used pairs of musical phrases played with piano sounds lasting thousands of milliseconds. It is possible that congenital blindness improves the ability to discriminate subtle pitch differences, but does not affect the processing of more abstract pitch intonation patterns such as music melody. The processing of music

melody needs to compute relationships between consecutive notes for which good pitch discrimination may be necessary but insufficient.

Interestingly, our study revealed for the first time that the blind performed better than the sighted on rhythm discrimination using the MET. Musical rhythm perception is not a purely auditory process; rather, it is motoric in nature, and the rhythm of timely movements is closely connected with the rhythm of music (Levitin *et al.*, 2018). Without the help of visual information, blind individuals may need to develop other abilities such as improved hearing and temporal sensitivity, which play an important role in sensorimotor learning and social development from early on. Temporal sensitivity can be essential to multisensory integration of hearing and tactile perception to facilitate object representation, spatial organization, locomotion, speech acquisition, and other higher level skills such as reading and writing. These activities can reinforce and enhance sensorimotor functions such as coordination and orientation in space and time among the visually impaired individuals. Because synchronizing movements to the musical rhythm is inherently important for music, the improved sense of rhythm in body movement might have a positive influence on the perception and production of musical rhythm, reflecting the cross-modal generalization effect during rhythm processing. This temporally-mediated embodied cognition account from a developmental perspective to explain rhythm perception advantages in the blind individuals is not fully consistent with recent findings of learning advantage for nonmetrical but not metrical rhythm from early-blind individuals who do not speak a tonal language (Carrara-Augustenborg and Schultz, 2017). Thus further comparative studies on the blind and sighted people are necessary to assess the relative contributions of native language experience, musical training, and listening conditions at different developmental stages.

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