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Musical experience facilitates lexical tone processing among Mandarin speakers: Behavioral and neural evidence

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ABSTRACT

Music and speech share many sound attributes. Pitch, as the percept of fundamental frequency, often occupies the center of researchers' attention in studies on the relationship between music and speech. One widely held assumption is that music experience may confer an advantage in speech tone processing. The cross-domain effects of musical training on non-tonal language speakers' linguistic pitch processing have been relatively well established. However, it remains unclear whether musical experience improves the processing of lexical tone for native tone language speakers who actually use lexical tones in their daily communication. Using a passive oddball paradigm, the present study revealed that among Mandarin speakers, musicians demonstrated enlarged electrical responses to lexical tone changes as reflected by the increased mismatch negativity (MMN) amplitudes, as well as faster behavioral discrimination performance compared with age- and IQ-matched nonmusicians. The current results suggest that in spite of the preexisting long-term experience with lexical tones in both musicians and nonmusicians, musical experience can still modulate the cortical plasticity of linguistic tone processing and is associated with enhanced neural processing of speech tones. Our current results thus provide the first electrophysiological evidence supporting the notion that pitch expertise in the music domain may indeed be transferable to the speech domain even for native tone language speakers.

1. Introduction

About two-thirds of the world's languages are tonal and are spoken by at least one-third of the global population (Yip, 2002). In a tone language, the pitch of the voice is used to convey word meaning in addition to its general function in expressing emphasis, contrast, and other subtle emotional information in speech intonation commonly found in all languages. The ability to speak a tone language seems to be acquired effortlessly in most native speakers, similar to how language is acquired in non-tonal languages. However, there is a special minority who show compromised speech tone perception due to developmental conditions such as dyslexia (Zhang et al., 2012) or congenital amusia (Nan et al., 2010). These individuals demonstrate characteristic difficulties in discriminating speech tone variations as reflected by both behavioral (Nan et al., 2010; Yang et al., 2014) and electrical responses to tone changes (Nan et al., 2016; Zhang et al., 2012). Because pitch is a predominant unit in music, music training might confer benefits in ameliorating these difficulties in speech tone perception. However, to our knowledge, music training's speech tone benefits have been demonstrated only in non-tonal language speakers. Paradoxically, for native tone language speakers whose use of lexical tones is critical in daily communication, this effect remains unclear. Hence, our current study examined whether music experience is linked to better speech tone perception among native tone language speakers using a cross-sectional approach.

Music experience has been associated with enhanced speech tone perception in non-tonal language speakers. Even when unfamiliar with tone languages, musicians speaking non-tonal languages outperformed nonmusicians in behavioral Mandarin tone identification tasks (Lee and Hung, 2008), showing more accurate brainstem encoding of speech tones (Bidelman et al., 2011; Wong et al., 2007) and more sensitive cortical electrical responses to tone changes (Chandrasekaran et al., 2009). Presumably, the musicians' advantage in foreign speech tone perception can be traced back to musicians' prominent abilities in processing speech prosody. Children with musical experience outperformed their nonmusician peers in processing speech prosody as reflected by both behavioral and electrical measures (Magne et al., 2006). Similar results have also been found with adult musicians in processing speech prosody in both native (Schon et al., 2004) and foreign

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languages (Marques et al., 2007). Longitudinal music training research suggests that this close relationship between music experience and speech prosody perception might indeed be causal, as 6 months of music training led to enhanced speech prosody discrimination compared with 6 months of painting training (Moreno et al., 2009).

Theoretically, in a non-tonal language background, musicians' advantage in processing lexical tones has been speculated to be based on short-term plasticity in the cortical responses, such as mismatch negativity (MMN) (Chandrasekaran et al., 2009), induced by corticofugal mechanisms (Suga et al., 2003). It is assumed that musicians' long-term musical training in musical pitch processing may be transferred to the behaviorally irrelevant linguistic tones (Chandrasekaran et al., 2009). It is thus interesting to ask, in a tone language background, when the linguistic tones are already behaviorally relevant, is there still a tone perception advantage for musicians? Based on the extended OPERA (Overlap, Precision, Emotion, Repetition, and Attention) hypothesis proposed by Patel (2014), musical training involves more precise pitch distinctions than what is required to learn a tone language. A small pitch interval such as one semitone can be perceptually distinct (e.g., the difference between an in-key and an out-of-key note), whereas in speech the pitch contrasts are normally more coarse-grained (Patel, 2014). Hence, one may predict that, even for native tone language speakers, it is quite possible to find an advantage in musicians over nonmusicians in linguistic tone processing.

However, the existing research on the relationship between music experience and speech tone perception among tonal language speakers is less clear. When learning a new tone language such as Cantonese, native Thai speakers with musical experience outperformed those without musical experience in tone identification (Cooper and Wang, 2012). However, in a recent study examining Mandarin-speaking musicians' categorical perception of lexical tones in comparison to nonmusicians, the authors showed that both musicians and nonmusicians demonstrated similar results in lexical tone discrimination and identification (Wu et al., 2015). Musicians outperformed nonmusicians only in discriminating within-category lexical tones (Wu et al., 2015). This study suggests that the tone advantage in musicians is very subtle, if not fully observable. Similarly, in another study (Mok and Zuo, 2012), musical experience facilitated lexical tone perception for non-tonal language speakers, but showed no beneficial effect in Cantonese speakers. As also noted by the authors (Mok and Zuo, 2012), the null transfer effects in lexical tone perception from music experience in Cantonese speakers might be attributed to the lack of sensitivity in their behavioral task and related measures. These inconsistent data call for further research, especially research with more precise measures provided by brain-imaging techniques, to examine the relationship between musicianship and speech tone perception in native tone language speakers.

In the current study, to determine whether musical experience in tone language speakers confers benefits in speech tone perception, we compared both MMN (Näätänen et al., 2007) and behavioral performance in speech tone discrimination between Mandarin-speaking musicians and nonmusicians. The MMN peaks approximately 100–250 ms after stimulus onset due to a mismatch between a rare deviant sound and a repetitive standard sound in an oddball paradigm (Näätänen et al., 2007). It is fronto-centrally distributed and typically indexes automatic auditory change detection (Näätänen et al., 2007). A similarly distributed positivity (i.e., P3a) occurring at approximately 300 ms after stimulus onset may follow the MMN. The P3a is linked to attentional switching towards the deviant stimulus (Kujala et al., 2007). We hypothesized that Mandarin-speaking musicians would demonstrate larger electrical responses to tone changes than nonmusicians, in line with results from non-tonal language speakers (Chandrasekaran et al., 2009). However, given that both musicians and nonmusicians were native Mandarin speakers, their behavioral tone discrimination performance might not be distinguishable due to the ceiling effect (Mok and Zuo, 2012). As a control condition, we also measured both the MMN (including P3a) and behavioral performance in music pitch discrimination in the two groups. Presumably, musicians would exhibit larger electrical responses and better behavioral performance in pitch discrimination than nonmusicians (Marie et al., 2012).

2. Material and methods

2.1. Participants

Fourteen musicians (four males) and fourteen age- and IQ-matched controls (two males) participated in the experiment. All participants were native speakers of Mandarin Chinese who were recruited through internet advertising from universities in Beijing. All musicians were undergraduates or postgraduates who majored in music. They had received at least 8 years of continuous instrumental training (mean $\pm$ SD; 13.6 $\pm$ 2.2 years) and started before the age of 8 years old (mean $\pm$ SD; 5.9 $\pm$ 1.4 years), with about two hours of daily practice (mean $\pm$ SD; 2.9 $\pm$ 1.0 h). The main instruments practiced by participants were piano (12), flute (1), and guzheng (1). The guzheng is a Chinese traditional plucked musical string instrument that is also known as the Chinese zither. None of the controls had any formal music training. To rule out the possibility that abnormal music abilities of some of the controls increased the group difference, all controls were required to complete the Montreal Battery of Evaluation of Amusia (MBEA) (Peretz et al., 2003). Each control scored above the cut-off score of 71.7%, which corresponds to two SDs below the mean of the controls as obtained in our previous study (Nan et al., 2010). All participants were right-handed (Oldfield, 1971), exhibited normal hearing (i.e., $\leq$ 20 dB HL; 250–8000 Hz) and reported no history of neurological disorders. The two groups were not significantly different in age ($p=0.076$), performance IQ ($p=0.305$), or verbal IQ ($p=0.364$; Table 1) as measured by the Wechsler Adult Intelligence Scale-Revised by China (WAIS-RC; Gong, 1992). The experiment was approved by the Institutional Review Board at Beijing Normal University, and written consent was obtained from each participant.

2.2. Stimuli

Two syllables, /da1/ and /da2/, were constructed for the lexical tone condition, which shared the same phoneme but carried different tone contours (1 = level tone and 2 = rising tone; Fig. 1). The original stimuli were produced by a female native Mandarin speaker in a soundproof room and recorded at a sampling rate of 44.1 kHz using a Sony 60EC digital recorder. Two notes, G3 and C4, were synthesized with a piano-like timbre for the musical pitch condition (Fig. 1). The four sound stimuli were digitally normalized to 300 ms (including 10 ms rise/fall times) and 70 dB with Praat

Table 1
The demographic characteristics of the musicians and nonmusicians.

	Musicians ($n=14$)	Nonmusicians ($n=14$)
Mean age (range)	20.6 (18–27)	22.3 (19–25)
Male/female	4/10	2/12
Performance IQ (SD)	115.1 (9.5)	118.8 (8.9)
Verbal IQ (SD)	122.4 (8.9)	125.1 (6.5)

IQ and SD indicate the intelligence quotient and the standard deviation, respectively.