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Subgroup differences in the lexical tone mismatch negativity (MMN) among Mandarin speakers with congenital amusia

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ABSTRACT

The association/dissociation of pitch processing between music and language is a long lasting debate. We examined this music-language relationship by investigating to what extent pitch deficits in these two domains were dissociable. We focused on a special neurodevelopmental pitch disorder — congenital amusia, which primarily affects musical pitch processing. Recent research has also revealed lexical tone deficits in speech among amusics. Approximately one-third of Mandarin amusics exhibits behavioural difficulties in lexical tone perception, which is known as tone agnosia. Using mismatch negativities (MMNs), our current work probed lexical tone encoding at the pre-attentive level among the Mandarin amusics with (tone agnosics) and without (pure amusics) behavioural lexical tone deficits compared with age- and IQ-matched controls. Relative to the controls and the pure amusics, the tone agnosics exhibited reduced MMNs specifically in response to lexical tone changes. Their tone-consonant MMNs were intact and similar to those of the other two groups. Moreover, the tone MMN reduction over the left hemisphere was tightly linked to behavioural insensitivity to lexical tone changes. The current study thus provides the first psychophysiological evidence of subgroup differences in lexical tone processing among Mandarin amusics and links amusics' behavioural tone deficits to impaired pre-attentive tone processing. Despite the overall music pitch deficits, the subgroup differences in lexical tone processing in Mandarin-speaking amusics suggest dissociation of pitch deficits between music and speech.

1. Introduction

As the percept of the repetition rate of sound waveforms (frequency), pitch is an important characteristic of sound, playing essential roles in both music and language. A great deal of prior research has examined the relationship between music and language by investigating the transferability of *pitch expertise* across domains. Although ample research suggests a common neural architecture encoding pitch processing across domains (Besson, Chobert, & Marie, 2011; Bidelman, Gandour, & Krishnan, 2011; Bidelman, Hutka, & Moreno, 2013; Wong, Skoe, Russo, Dees, & Kraus, 2007), recent evidence indicates a music-language dissociation in pitch processing (Hutka, Bidelman, & Moreno, 2015; Nan & Friederici, 2013). We tackled this debate from another perspective, investigating this music-language relationship by examining to what extent *pitch deficits* in these two domains were dissociable.

In the music domain, the widely recognized pitch deficit affects a small portion (approximately 4%) of the general population, which is known as congenital amusia (hereafter amusics) (Peretz, 2001). The amusic individuals exhibit a characteristic musical pitch deficit (Foxton, Dean, Gee, Peretz, & Griffiths, 2004; Hyde & Peretz, 2004) that is neither of clear neurological origin nor due to a lack of musical exposure. Research suggests that congenital amusics may also have difficulties with pitch memory (Tillmann, Schulze, & Foxton, 2009; Albouy, Schulze, Caclin, & Tillmann, 2013; Gosselin, Jolicoeur, & Peretz, 2009; Williamson & Stewart, 2010; Williamson, McDonald, Deutsch, Griffiths, & Stewart, 2010), timbre processing (Marin, Gingras, & Stewart, 2012), and emotional prosody perception (Thompson, Marin, & Stewart, 2012).

Nonetheless, amusics' core deficit is related to musical pitch processing (Foxton et al., 2004; Hyde & Peretz, 2004). ERP studies from different research groups have demonstrated that amusics' auditory musical pitch processing might be intact, whereas their explicit judgment or awareness of pitch perception might be compromised (Peretz, Brattico, Jarvenpaa, & Tervaniemi, 2009; Mignault,

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Moreau, Robitaille, & Peretz, 2012; Moreau, Jolicoeur, & Peretz, 2013; Omigie, Pearce, Williamson, & Stewart, 2013). This interpretation is in line with brain-imaging results that have revealed structural abnormalities in the bilateral superior temporal and inferior frontal regions of amusics' brains (Hyde, Zatorre, Griffiths, Lerch, & Peretz, 2006; Hyde et al., 2007; Mandell, Schulze, & Schlaug, 2007). The associated abnormalities may reside not only in the auditory cortices (Albouy et al., 2013) but also in the temporo-frontal pathway that connects the auditory cortex to the inferior frontal region (Hyde, Zatorre, & Peretz, 2011; Loui, Alsop, & Schlaug, 2009; Albouy et al., 2013).

However, in the language domain, pitch deficits have rarely been reported alone in normal populations. Very often, they coexist with the condition of amusia. Accumulating evidence suggests that amusics are also impaired in linguistic tone processing at both the word (i.e., lexical tone, Liu et al., 2012; Nan, Sun, & Peretz, 2010; Tillmann et al., 2011) and sentence levels (i.e., intonation, Jiang, Hamm, Lim, Kirk, & Yang 2010; Jiang et al., 2012a; Liu, Patel, Fourcin, & Stewart, 2010; Patel, Foxton, & Griffiths, 2005).

The coexistence of pitch deficits in music and language may first appear to imply a close music-language association. However, the neural mechanisms that could account for the speech tone deficits have not been assessed as deeply as those underlying the music pitch deficits, i.e., amusia. So far, the neurophysiological nature of amusics' behavioural linguistic tone deficits remains largely unknown. To the best of our knowledge, there is only one study that has addressed possible abnormal event-related brain potentials in Mandarin-speaking amusics during speech intonation comprehension (Jiang et al., 2012a). In their study, inappropriate relative to appropriate intonation elicited a larger P600 and a smaller N100 in controls but not in amusics, which was taken as neurobiological evidence for intonation deficits in Mandarin-speaking amusics (Jiang et al., 2012a). Investigations of the neural mechanisms underpinning the linguistic tone deficits of amusics will expand our knowledge of the nature of amusia and consequently inform us about the possible optimal intervention options for helping to ameliorate the condition. Moreover, a deep understanding of the speech tone deficits in amusics will ultimately shed light on the intricate relationship between music and speech pitch processing.

Using mismatch negativities (MMNs), the current study probed pre-attentive lexical tone processing among native Mandarin-speaking amusics compared with age- and IQ-matched controls. It is well known that the auditory discrimination accuracy of speech sounds can be investigated with MMN, which is an automatic change-detection neural response in event-related brain potentials (ERPs) (Näätänen, Paavilainen, Rinne, & Alho, 2007). It indexes not only the behavioural discrimination accuracy but also the sensory memory traces of the preceding stimulation, forming the bases for change detection (Näätänen et al., 2007). More importantly, the MMN is localized in bilateral auditory and right frontal regions in the brain (Alain, Woods, & Knight, 1998), which converges with the affected auditory-fronal cortical network of pitch processing in amusics (Albouy et al., 2013; Hyde et al., 2011; Loui et al., 2009). Hence, the MMN seems well suited to examine the neurophysiological basis underlying amusics' lexical tone deficits. In our earlier studies (Nan et al., 2010; Yang, Feng, Huang, Zhang, & Nan, 2013), behavioural lexical tone deficits were found to be most prominent in a subgroup of amusics (hereafter 'tone agnosics'), whereas behavioural tone processing seemed to be unaffected in other amusics (hereafter 'pure amusics'). These two subgroups of amusics (i.e., pure amusics and tone agnosics) were both included in the current study.

We examined the MMN responses to tonal (/da2/ meaning 'to answer', 2 = rising tone) and tone-consonant (/ba2/, 'to pull out', 2 = rising tone) changes in a stream of standard stimuli (/da1/, 'to put up', 1 = level tone) of Mandarin-speaking pure amusics (amusics *without* lexical tone deficits) and tone agnosics (amusics *with* lexical tone deficits) compared to age- and IQ-matched controls. The tone-consonant deviant was different from the standard stimulus not only in terms of tone but also in terms of the consonant. Because amusics' speech difficulties are largely limited to linguistic tones (but see Wang & Peng, 2014; Jones, Lucker, Zalewski, Brewer, & Drayna, 2009; Jones, Zalewski, Brewer, Lucker, & Drayna, 2009 for possible phonological deficits in amusics), tone change detection was more likely to be physiologically affected than tone-consonant change detection.

As mentioned above, amusics' musical pitch deficits are primarily related to impaired pitch awareness, while pre-attentive encoding is intact (Moreau et al., 2013; Peretz et al., 2009). For example, Peretz and her colleagues reported that although amusics are behaviourally insensitive to semitone changes in a melody, amusics' brains can track quarter-tone mistuning, as reflected by their N200 responses (Peretz et al., 2009). These authors thus suggested that the amusics' neural processing of fine-grained pitch changes is intact and that they are only behaviourally unaware (Peretz et al., 2009). Moreau et al. (2013) followed up this line of research and re-examined amusics' brain responses to 25 cents (an eighth of a tone) or 200 cents (one whole tone) changes in an acoustical context. These authors observed normal MMN responses to both the 25 and 200 cents tone changes in amusics.

Similarly, in the current study, it is possible that despite their behavioural lexical tone difficulties, tone agnosics could exhibit MMN responses to lexical tone changes that are similar to those of the controls and pure amusics, which would suggest normal pre-attentive processing with possibly compromised behavioural awareness of the lexical tones among tone agnosics and resemble the findings regarding amusics' affected pitch awareness (Moreau et al., 2013; Peretz et al., 2009). Alternatively, tone agnosics might exhibit reduced MMNs in response to tone changes relative to the controls and pure amusics. This would indicate impaired pre-attentive lexical tone processing in the tone agnosics. Moreover, for pure amusics, despite the music pitch deficits, their behavioural lexical tone processing seems intact. It would be interesting to examine whether a similar integrity in lexical tone processing existed at the neurophysiological level as reflected by tone MMNs.

2. Material and methods

2.1. Participants

Twelve neurologically healthy controls (five females), twelve pure amusics (five females), and eight tone agnosics (three females) participated in the current study. All participants were native speakers of Mandarin Chinese who were recruited through internet advertising from universities in Beijing. None of the participants had any formal music training. All of the participants were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). All of the participants' audiometric thresholds were equal to or below 20 dB HL for octaves ranging from 250 to 8000 Hz. The participants were assessed with the Montreal Battery of Evaluation of Amusia (MBEA) (Peretz, Champod, & Hyde, 2003), which includes three pitch-based tests (scale, contour and interval), two time-based tests (rhythm and meter), and one memory test. Each participant in the pure amusic and tone agnosic groups scored below the cut-off score of 71.7%, which corresponded to two SDs below the mean of the controls as obtained in our previous study (Nan et al., 2010). Additionally, eight tone agnosics were identified as a special group of participants who not only had musical pitch deficits, as measured by the MBEA, but also had lexical tone difficulties, as measured with the lexical tone perception