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Language experience enhances early cortical pitch-dependent responses

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A B S T R A C T

Pitch processing at cortical and subcortical stages of processing is shaped by language experience. We recently demonstrated that specific components of the cortical pitch response (CPR) index the more rapidly-changing portions of the high rising Tone 2 of Mandarin Chinese, in addition to marking pitch onset and sound offset. In this study, we examine how language experience (Mandarin vs. English) shapes the processing of different temporal attributes of pitch reflected in the CPR components using stimuli representative of within-category variants of Tone 2. Results showed that the magnitude of CPR components (Na–Pb and Pb–Nb) and the correlation between these two components and pitch acceleration were stronger for the Chinese listeners compared to English listeners for stimuli that fell within the range of Tone 2 citation forms. Discriminant function analysis revealed that the Na–Pb component was more than twice as important as Pb–Nb in grouping listeners by language affiliation. In addition, a stronger stimulus-dependent, rightward asymmetry was observed for the Chinese group at the temporal, but not frontal, electrode sites. This finding may reflect selective recruitment of experience-dependent, pitch-specific mechanisms in right auditory cortex to extract more complex, time-varying pitch patterns. Taken together,

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these findings suggest that long-term language experience shapes early sensory level processing of pitch in the auditory cortex, and that the sensitivity of the CPR may vary depending on the relative linguistic importance of specific temporal attributes of dynamic pitch.

1. Introduction

Pitch is a salient perceptual attribute that plays an important role in language and music (Oxenham, 2012; Plack, Oxenham, & Fay, 2005). Despite similarities in pitch processing between domains, empirical evidence supports the view that neural representations of pitch may be shaped by its functional properties in a given domain of expertise. Tone languages are especially useful for studying the effects of functional properties of pitch that are phonemic at the syllable level (Maddieson, 1978; Yip, 2002). It is well established that dynamic variations in voice fundamental frequency (F_0) provide the dominant acoustic cue for tonal recognition (Abramson, 1962; Gandour, 1994; Klatt, 1973; Xu, 2001). In the case of lexical tone, several cross-language (or cross-domain) studies have revealed experience-dependent neural plasticity at both cortical and subcortical levels of the brain (see Gandour, 2006; Gandour & Krishnan, 2014; Krishnan, Gandour, & Bidelman, 2012; Zatorre & Baum, 2012; Zatorre & Gandour, 2008, for reviews). Thus, tone languages not only give us a physiologic window to evaluate how neural representations of linguistically-relevant pitch attributes emerge along the early stages of sensory processing in the hierarchy, but they may also shed light on the nature of interaction between early sensory levels and later higher levels of cognitive processing in the human brain.

Pitch is a multidimensional perceptual attribute that relies on several acoustic dimensions. In particular, F_0 *height* and *contour* (i.e., nonlinear change in pitch between onset and offset) have been revealed to be important, experience-dependent dimensions of pitch underlying the perception of lexical tone (Francis, Ciocca, Ma, & Fenn, 2008; Gandour, 1983; Gandour & Harshman, 1978; Huang & Johnson, 2011; Khouw & Ciocca, 2007). These same pitch dimensions have been targeted in recent studies of tonal processing in the human brain. Using the mismatch negativity (MMN), Chinese listeners, relative to English, were more sensitive to pitch contour than pitch height in response to Mandarin tones, indicating that MMN may serve as a neural index of the relative saliency of underlying dimensions of pitch that are differentially weighted by language experience (Chandrasekaran, Gandour, & Krishnan, 2007). In Cantonese, the magnitude and latency of MMN were sensitive to the size of pitch height change, while the latency of P3a (an automatic attention shift induced by the detection of deviant features in the passive oddball paradigm) captured the presence of a change in pitch contour (Tsang, Jia, Huang, & Chen, 2011). In Mandarin, pitch height and contour dimensions associated with lexical tone were reported to be lateralized respectively to the right and left hemispheres (Wang, Wang, & Chen, 2013). Their findings, however, may not be attributable to pitch exclusively because standard/deviant tonal contrasts were not phonologically equivalent across experimental conditions. A within-category contrast was used for the height condition; an across-category contrast for the contour condition. The categorical status of tonal contrasts provides a more plausible explanation of the observed pattern of hemispheric laterality (Xi, Zhang, Shu, Zhang, & Li, 2010; Zhang et al., 2011). Though contour and height are important dimensions that are implicated in early, cortical pitch processing, the MMN itself is *not* a pitch-specific response. It is comprised of both auditory and *cognitive* mechanisms of frequency change detection in auditory cortex (Maess, Jacobsen, Schroger, & Friederici, 2007). This parallel processing is consistent with the near-simultaneity of neurophysiological indicators (EEG/MEG) of psycholinguistic information in the first 200–250 ms (Pulvermuller, Shtyrov, & Hauk, 2009).

The quest to discover an early, preattentive cortical brain response exclusively to pitch began in earnest around the turn of this century. Magnetoencephalography (MEG) was used to study

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