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Research Report

Dissociable pitch processing mechanisms in lexical and melodic contexts revealed by ERPs

Yun Nan[a,*], *Angela D. Friederici*[b], *Hua Shu*[a], *Yue-jia Luo*[a]

[a]*State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, 19 Xin-Wai St., Hai-Dian District, Beijing 100875, PR China*

[b]*MPI for Human Cognitive and Brain Sciences, Leipzig, Germany*

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ABSTRACT

The current ERP study examined the neural substrates for pitch processing in music and in tonal language with phrases ending in either congruous or incongruous pitches. In a tonal language, like Chinese, pitch is lexically relevant as it can change the meaning of words, and it could therefore be hypothesized that pitch information under this condition is processed differently from musical pitch. Female Chinese musicians were chosen as listeners for their ample exposure to music and a tonal language. Pitch violations in both domains were associated with a frontally distributed late positive component (LPC). In addition to evoking an N400 for language condition, pitch processing as revealed by the LPCs is left lateralized for tonal language and right lateralized for music. We propose that our data may imply different brain resources engaging in pitch processing depending on whether its function is lexical, as in a tonal language like Chinese, or musical in nature.

1. Introduction

Pitch, as a basic acoustic element in music and language, has attracted much attention from cognitive neuroscientists. How our brains process pitch is a fundamental and much debated question in the field of music and language perception. Depending upon different functions in context, language pitches could be roughly divided into two categories: lexical and sentential. Studies on pitch processing in music and language (at both lexical and sentential levels) domains, to the best of our knowledge, have yet reached a consensus. While some studies argue for a difference between pitch processing in music and language, others indicate a large overlap.

The related comparative music-language studies, which have been published in recent years, mainly revealed shared neural mechanisms in both melodic and sentential pitch processing. An electrophysiological study comparing pitch processing in music with pitch processing in a nontonal language (French), in which pitch carries syntactic rather than lexical information, reported similar brain potentials in the two domains (Schon et al., 2004). This study also suggests that extensive musical training influences the perception of pitch contour in spoken language (Schon et al., 2004). Using the same manipulation, Magne et al. (2006) replicated the transfer effect of pitch processing from music to language (French) in 8-year-olds.

When shifted from a sentential context to a lexical one, pitch is vital in determining word meaning rather than signaling intonation or stress. It is thus not surprising that, the neural substrates underlying lexical and sentential pitch processing in language, as suggested by some studies, seem to be different (Gandour et al., 2000; Wong et al., 2004).

* *Corresponding author*. Fax: +86 10 58806154.
E-mail address: dr_yunnan@yahoo.com.cn (Y. Nan).

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Unlike related research on sentential and melodic pitch, there is currently no published comparative music-language research on lexical level. Nonetheless, there are some studies in support of the view of unshared neural substrates focused on lexical tone processing. Studies with aphasic and brain lesion patients already do provide some evidence with respect to the neural basis of the processing of tonal languages. In Chinese aphasic patients with left hemisphere lesions lexical tone identification, as opposed to intonation pattern identification, was reported to be greatly compromised (Liang and van Heuven, 2004). Lexical tone processing in tonal languages, as compared to tone processing in nontonal languages, seems to be a function of the left hemisphere (Wong et al., 2004; Wang et al., 2001; Klein et al., 2001). Identification of lexical tones appears to be impaired in Thai aphasics with left-sided brain lesion (Gandour and Dardarananda, 1983; Gandour et al., 1992) and Mandarin (Packard, 1986; Naeser and Chan, 1980). Neuroimaging studies of lexical tone perception revealed activation in left inferior frontal areas (Gandour et al., 2000) and left anterior insular cortex (Wong et al., 2004), whereas studies of non-lexical tone processing reported activation of homologous brain areas in the right hemisphere (Zatorre et al., 1992; Wong et al., 2004). Furthermore, a study on congenital amusic individuals showed a reduction in the white matter concentration in the right inferior frontal gyrus which correlated with performance on pitch-related music tasks, implicating that right inferior frontal regions may play a role in musical pitch encoding and melodic pitch memory (Hyde et al., 2006). These results point towards a neural dissociation between lexical-based and melodic-based pitch processing.

In contrast, shared resources for pitch processing in music and language were also reported for the level of lexical tone by Wong et al. (2007) who showed that American-English-speaking musicians demonstrated higher performance at identifying and discriminating lexical tones than their non-musician counterparts. Moreover, a recent correlational study (Slevc and Miyake, 2006) revealed that musical ability predicted phonological ability (both receptive and productive) in a second language use. These studies support the notion that the ability of pitch processing in music could be carried over to language domain, even on lexical level, specifically.

From the above mentioned studies, however, it is difficult to draw a final conclusion on the possible neural patterns engaged in pitch processing across domains. More comparative music-language studies, especially on lexical level, could help us gain deeper insights than could be obtained by exploring each domain separately, as suggested by Patel (2008a).

A direct pitch processing contrast between tonal language (lexical-based) and music (melodic-based), to our knowledge, has yet to be made. Such a comparison might be potentially helpful, not only to identify the neural mechanism underlying pitch processing in music and language, but to add new evidence to the field mainly based on nontonal language research.

The present study sets out to investigate neural correlates of pitch processing in tonal language (Chinese) and music, as reflected by ERP components. Here we will use event-related brain potential (ERP) to investigate the neural correlates of pitch processing in music and a tonal language, namely Chinese, in which pitch is of lexical relevance. Electrophysiologically, the processing of incongruous tones in musical melody, has typically been linked to a centroparietally distributed positivity, known as the P600 (Besson and Macar, 1987; Besson and Faita, 1995). It appears that rule-based as well as memory-based tone violations within melodies both revealed a centroparietal positivity (Miranda and Ullman, 2007). Comparing pitch processing in music and in non-tonal language at the sentential level, Schon et al. (2004) and Magne et al. (2006) have reported a posterior late positivity as a shared ERP marker reflective of pitch processing across domains. When pitch information is relevant for the meaning of a sentence, i.e. the placement of accent, violations yielded an N400 effect in a tonal language (Li et al., 2008), similar to violations in lexical tone in Chinese (Brown-Schmidt and Canseco-Gonzalez, 2004; Schirmer et al., 2005).

These data suggest that the processing of pitch information and the related brain activation pattern is dependent upon its cognitive function rather than its acoustical nature.

In the present experiment, we investigated congruously and incongruously ending music phrases and tonal language (Chinese) phrases. Based on previous brain imaging and patient work we expected an involvement of the right hemisphere for music processing and an involvement of the left hemisphere when processing lexically relevant pitch in language. We hypothesized that this should be reflected in the distribution of the late positivity (LPC). Because tone violation in phrases of Chinese also calls for lexical-semantic processing, and a N400 component (Kutas and Hillyard, 1980; Liu et al., 2006) linked to lexical-semantic processing is expected in the language condition.

As there is great variability in the individual's brain responses to music due to different levels of musical expertise (Seung et al., 2005; Satoh et al., 2001; Shahin et al., 2003; Koelsch et al., 2005; Morrison et al., 2003; Aydin et al., 2005) and to gender (Koelsch et al., 2003; Lee et al., 2003; Johnson et al., 1996), the choice of the participants in the current study has been determined by these two factors. Chinese musicians were chosen to ensure a certain level of expertise not only in processing lexical tones in a tonal language but also pitches in music. Females were chosen because it has been shown that they have less left lateralized hemispheric involvement in pitch processing if compared to males (Gaab et al., 2003). Thus, gender could have interfered with the predicted hemispheric differences as a function of auditory input. To reduce the inter-subject variance, the current study used Chinese female musicians within the age range of 19–25 as participants.

2. Results

2.1. *Behavioral results*

Behavioral results showed that congruously-ended language phrases were easier to categorize than congruous musical ones ($F_{1,11}=27.055$, $p<0.001$; hit rate for congruous language phrases: 97.1±0.9%; hit rate for congruous musical phrases: 91.4±1.2%), whereas no statistical difference in performance between incongruous music (hit rate: 92.6±2.4%) and language phrases (hit rate: 92.0±1.2%) was obtained. This is consistent with the observed marginal interactions between MODE