Journal of Neurolinguistics 41 (2017) 38–49

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Research paper

Language-dependent changes in pitch-relevant neural activity in the auditory cortex reflect differential weighting of temporal attributes of pitch contours

Ananthanarayan Krishnan [a, **], Jackson T. Gandour [a, *], Yi Xu [b], Chandan H. Suresh [a]

[a] Department of Speech Language Hearing Sciences, Purdue University, West Lafayette, IN, USA
[b] Department of Speech, Hearing and Phonetic Sciences, University College London, UK

A R T I C L E I N F O

Article history:
Received 22 May 2016
Received in revised form 7 September 2016
Accepted 14 September 2016
Available online 16 September 2016

Keywords:
Auditory
Pitch encoding
Iterated rippled noise
Cortical pitch response
Experience-dependent neuroplasticity
Mandarin

A B S T R A C T

There remains a gap in our knowledge base about neural representation of pitch attributes that occur between onset and offset of dynamic, curvilinear pitch contours. The aim is to evaluate how language experience shapes processing of pitch contours as reflected in the amplitude of cortical pitch-specific response components. Responses were elicited from three nonspeech, bidirectional (falling-rising) pitch contours representative of Mandarin Tone 2 varying in location of the turning point with fixed onset and offset. At the frontocentral Fz electrode site, Na–Pb and Pb–Nb amplitude of the Chinese group was larger than the English group for pitch contours exhibiting later location of the turning point relative to the one with the earliest location. Chinese listeners' amplitude was also greater than that of English in response to those same pitch contours with later turning points. At lateral temporal sites (T7/T8), Na–Pb amplitude was larger in Chinese listeners relative to English over the right temporal site. In addition, Pb–Nb amplitude of the Chinese group showed a rightward asymmetry. The pitch contour with its turning point located about halfway of total duration evoked a rightward asymmetry regardless of group. These findings suggest that neural mechanisms processing pitch in the right auditory cortex reflect experience-dependent modulation of sensitivity to weighted integration of changes in acceleration rates of rising and falling sections and the location of the turning point.

1. Introduction

Pitch is an important information-bearing perceptual attribute that provides an excellent window for studying language-dependent effects on pitch processing at both subcortical and cortical levels. Tone languages are especially advantageous for investigating the linguistic use of pitch because variations in pitch patterns at the syllable level may be lexically significant (Laver, 1994, p. 465). Neural representation of pitch may be influenced by one's experience with language (or music) at

* Corresponding author. Purdue University, Department of Speech Language Hearing Sciences, Lyles-Porter Hall, 715 Clinic Drive, West Lafayette, IN 47907-2122, USA.
** Corresponding author. Purdue University, Department of Speech Language Hearing Sciences, Lyles Porter Hall, 715 Clinic Drive, West Lafayette, IN 47907-2122, USA.
E-mail addresses: rkrish@purdue.edu (A. Krishnan), gandour@purdue.edu (J.T. Gandour), yi.xu@ucl.ac.uk (Y. Xu), hs0@purdue.edu (C.H. Suresh).

http://dx.doi.org/10.1016/j.jneuroling.2016.09.005
0911-6044/

subcortical as well as cortical levels of processing (for reviews, see Gandour & Krishnan, 2016; Johnson, Nicol, & Kraus, 2005; Kraus & Banai, 2007; Krishnan & Gandour, 2009, 2014; Patel & Iversen, 2007; Tzounopoulos & Kraus, 2009; Zatorre & Baum, 2012; Zatorre & Gandour, 2008). Of special interest herein, Jia, Tsang, Huang, and Chen (2015) have recently demonstrated—using the mismatch negativity (MMN)—that processing of lexical tone relies on both acoustic and linguistic factors at an early cortical stage of processing.

Experience-dependent enhancement of pitch relevant phase-locked neural activity in the auditory brainstem has been observed consistently for rapidly-changing pitch sections that occur after the turning point of high rising Mandarin Tone 2 (T2) in nonspeech contexts (Bidelman, Gandour, & Krishnan, 2011; Krishnan, Swaminathan, & Gandour, 2009). In response to a continuum of nonspeech variants of T2 varying in acceleration rate (Krishnan, Gandour, Smalt, & Bidelman, 2010), both Mandarin- and English-speaking groups show decreasing pitch strength of brainstem responses with increasing acceleration rates. Yet Chinese are more resistant to degradation even in response to scaled variants of T2 with higher acceleration rates that fall proximal to or outside the normal voice pitch range. Across studies of T2 at the level of the auditory brainstem, the location of the turning point was a constant.

At the level of the cerebral cortex, the EEG-derived, human cortical pitch response (CPR) transient components (Na–Pb, Pb–Nb) reveal that Mandarin-speaking natives are sensitive to changes in pitch acceleration as elicited by three within-category, nonspeech variants of T2 (Krishnan, Gandour, Ananthakrishnan, & Vijayaraghavan, 2014). These stimuli varied both in duration and location of turning point. Neural markers flag different temporal attributes of a dynamic pitch contour: onset of temporal regularity (Na); changes in temporal regularity between onset and offset (Na–Pb, Pb–Nb). Pc–Nc marks unambiguously the stimulus offset. A strong correlation with pitch acceleration is observed for Na–Pb and Pb–Nb, putative indices of pitch-relevant neural activity associated with the more rapidly-changing sections of the pitch contour. A cross-language study shows that the magnitude of CPR components Na–Pb and Pb–Nb is larger for Chinese than English listeners in response to all three variants of T2 (Krishnan, Gandour, Ananthakrishnan, & Vijayaraghavan, 2015). Using the same set of pitch stimuli as in Krishnan et al. (2010), Chinese listeners show greater amplitude than English for both Na–Pb and Pb–Nb at frontocentral (Fz) and temporal (T7/T8) electrode sites in response to the two pitch contours with acceleration rates that fall inside the normal voice pitch range, i.e., those that fall within the bounds of one's native language (Krishnan, Gandour, & Suresh, 2015a). As indexed by Na–Pb and Pb–Nb amplitude at the temporal sites, a right-sided preference was observed for the Chinese group only. Amplitude of the Chinese group was greater than that of the English only over the right temporal site. We infer that the neural mechanism(s) underlying processing of pitch in the right auditory cortex reflect experience-dependent modulation of sensitivity to changes in acceleration rates on the section of the pitch contour from turning point to offset in T2.

To extend this line of research on sensitivity of cortical responses to changes in the temporal dynamics throughout an entire pitch contour, we now recognize the need to design stimulus sets that include the following variables: onset, offset, and turning point. A pitch contour necessarily involves a movement from its onset to offset. What happens between onset and offset can best be expressed acoustically as changes in acceleration (or velocity). In natural speech production, this movement is dynamic, and curvilinear in nature. Using Cantonese lexical tones with varying onsets and offsets (Tsang, Jia, Huang, & Chen, 2011), the size or latency of MMN did not vary depending upon the location of the turning point in pitch contours. The latency of P3a—ERP component associated with automatic switching of attention induced by unexpected change in stimulus event—was delayed to the same extent irrespective of the location of the turning point. To the best of our knowledge, there is no published report of a scalp-recorded, event-related brain potentials (ERP) study of pitch processing in which the turning point is systematically varied while holding onset, offset and duration constant (cf. behavioral; Moore & Jongman, 1997). In previous studies of Mandarin lexical tones, turning point covaried with duration (Krishnan et al., 2014; Krishnan et al., 2015) or turning point was fixed along with onset and duration (Krishnan, Gandour, & Suresh, 2015a), or location of turning points were invariant within stimulus sets (Bidelman & Lee, 2015).

As our knowledge grows about the CPR, it is important to establish the lower and upper bounds of its sensitivity to various pitch attributes (e.g., acceleration). We have therefore incorporated a quantitative model for generating voice fundamental frequency (F0) contours of speech (Prom-on, Xu, & Thipakorn, 2009). This model is based on biophysical and linguistic assumptions about the mechanisms of F0 production. It permits us to design stimulus sets that address specific research questions regarding the sensitivity of cortical and/or brainstem responses to changes in the temporal dynamics of a pitch contour. In this study, the stimulus set represents a continuum of bidirectional pitch contours that exhibit changes in acceleration in two sections of the pitch contour. The first section spans from onset to turning point; the second section, from turning point to offset. We are able to change acceleration systematically in both sections by holding F0 onset and offset constant, and progressively delay the temporal location of the turning point in the pitch contour. The result is a three-step, F0 turning point continuum in which pitch contours represent within-category variants of T2 that may be produced on isolated monosyllables.

The specific aim of this study is to determine how changes in the temporal location of the turning point in the bidirectional pitch contours influence amplitude of CPR components as a function of language experience (Mandarin, English). Stimulus comparisons at the frontocentral electrode site allow us to assess the effects of changes in location of the turning point. At the right temporal site, the pattern of changes in CPR components is expected to reflect temporally distinct, language-dependent differential weighting of sensory and extrasensory effects. More generally, we infer that enhancement of pitch-relevant neural activity reflects optimal, differentially weighted, integration of pitch relevant neural activity to changes in acceleration rates of the falling and rising segments and the location of the turning point.