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PROCESSING CANTONESE LEXICAL TONES: EVIDENCE FROM ODDBALL PARADIGMS

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Abstract—Two event-related potential (ERP) experiments were conducted to investigate whether Cantonese lexical tones are processed with general auditory perception mechanisms and/or a special speech module. Two tonal features (f0 direction and f0 height deviation) were manipulated to reflect acoustic processing, and the contrast between syllables and hums was used to reveal the involvement of a speech module. Experiment 1 adopted a passive oddball paradigm to study a relatively early stage of tonal processing. Mismatch negativity (MMN) and novelty P3 (P3a) were modulated by the interaction between tonal feature and stimulus type. Similar interactions were found for N2 and P3 in Experiment 2, where more in-depth tonal processing was examined with an active oddball paradigm. Moreover, detecting tonal deviants of syllables elicited N1 and P2 that were not found in hum detection. Together, these findings suggest that the processing of lexical tone relies on both acoustic and linguistic processes from the early stage. Another noteworthy finding is the absence of brain lateralization in both experiments, which challenges the use of a lateralization pattern as evidence for processing lexical tones through a special speech module.

Key words: lexical tone processing, ERPs, passive/active oddball.

INTRODUCTION

In more than 40% of all spoken languages tonal information can serve to distinguish lexical items just as phonemes do (Maddieson, 2013). Obviously, our understanding of speech perception will be incomplete without considering lexical tone processing. Chinese is the most widely spoken tonal language, and different Chinese dialects have developed highly distinctive tonal systems (Gandour, 1983). Cantonese (a dialect widely spoken in South China) is a particularly interesting dialect for examining lexical tone processing because of its complex tonal system. There are six distinctive lexical tones in Cantonese, including three level, two rising, and one falling tone (Fig. 1).

Given the obvious differences between tones and phonemes (e.g., acoustic correlates, information values, etc.), some researchers have been interested in comparing the related processes (e.g., Cutler and Chen, 1997; Schirmer et al., 2005). For example, using a passive oddball paradigm, Luo et al. (2006) demonstrated that tonal deviants triggered stronger mismatch negativities (MMNs) in the right hemisphere (RH), while responses to consonantal deviants were stronger in the left hemisphere (LH), suggesting that tonal and phonemic processes rely on at least partially different hemispheres. These results are also related to the debate of whether speech perception is best explained by general auditory processes or a specialized speech module (Carbonell and Lotto, 2014; Diehl et al., 2004). Note that lexical tone serves a linguistic function, but its primary acoustic correlate, f0, also takes up non-linguistic functions in music or emotional expression. If a language module does exist, it should be responsible for processing all linguistic information, including lexical tone. In other words, the "function" of lexical tone presumably determines its locus of processing. However, if speech is processed by general audition, then lexical tone, music, and other f0-dependent information should be processed similarly because they share the same "acoustic" properties. Based on the proposal that the LH and RH are responsible for language and musical processing, respectively (Zatorre et al., 2002; Nan et al., 2009), it is possible to hypothesize that the LH should be more strongly activated by tonal vs. musical information if it is processed based on its linguistic function. On the contrary, stronger activation of lexical tone in the RH, as in Luo et al. (2006), is considered as evidence for the acoustic processing view of tonal information.

Besides the results of Luo et al. (2006), further evidence for the acoustic view has been obtained in dichotic listening, where a left-ear advantage (i.e., the RH advantage) for tone detection was found (Jia et al., 2013). On

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Abbreviations: ANOVA, analysis of variance; EEG, electroencephalogram; EOG, electrooculogram; ERP, event-related potential; fMRI, functional magnetic resonance imaging; f0, fundamental frequency; ISI, inter-stimulus interval; LH, left hemisphere; MMN, mismatch negativity; P3a, novelty P3; RH, right hemisphere.

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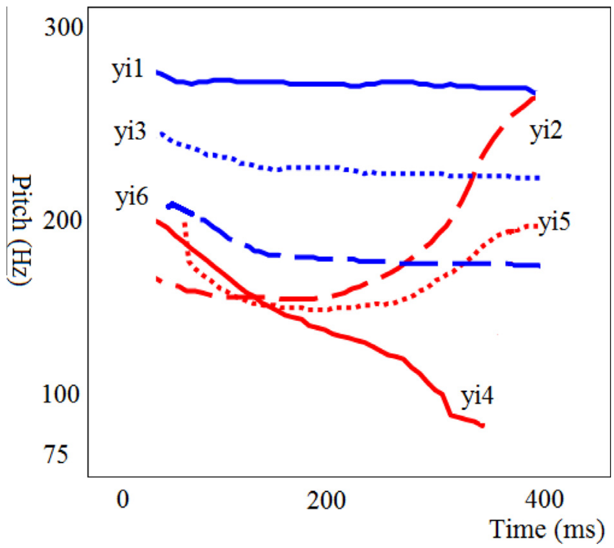

Fig. 1. f0 profile of the stimuli.

the other hand, LH activation during lexical tone processing, which supports the functional view, can also be found in the literature. For example, Gandour et al. (2003) conducted a functional magnetic resonance imaging (fMRI) study and showed that discrimination of lexical tones activated the left frontal and temporal regions. Similar evidence was also obtained in a positron emission topography (PET) study (Hsieh et al., 2001). To reconcile the discrepant findings of brain lateralization during lexical tone processing, Luo et al. (2006) proposed a two-stage model of lexical tone processing: At the early stage, the acoustic features of lexical tone dominate and are processed in the RH. At the later stage, the speech module starts to be involved, leading to a shift of processing locus from RH to LH. Because the exact stage of processing that an experiment taps into depends on measurements (event-related potential ERP vs. fMRI), task demands, and stimulus properties, this leads to the apparent instability of the lateralization pattern observed.

However, not all data in the literature are consistent with the mentioned two-stage model. For example, Ge et al. (2015) developed models of Chinese and English speech comprehension on the basis of large-scale fMRI data and found that the right anterior temporal cortex is activated only for Chinese, which they attributed to the processing demand of the lexical tone. Thus, fMRI data can also reveal RH activation of tonal information. More importantly, some researchers also adopted the MMN procedure but failed to replicate the findings by Luo et al. (2006). For example, Chandrasekaran et al. (2007) measured ERP activities at F3, Fz, and F4, and found no differences in the MMN responses across electrode positions. Using dipole analysis, Gu et al. (2013) even demonstrated that the source of lexical tone MMN was located in the LH, rather than in the RH.

Given its theoretical significance, it is desirable to further investigate the nature of lexical tone processing. This study aims to examine the issue by manipulating task demand and stimulus property systematically. Such an approach allows us to examine not just the related main effects but also the interaction of acoustic and linguistic factors. In particular, we recorded ERP as participants performed passive oddball (Experiment 1) and active oddball tasks (Experiment 2). In a typical passive oddball paradigm, participants are instructed to focus on watching a silent movie and ignore the auditory stimuli. The results obtained with this procedure are typically interpreted as "pre-attentive" or "attention-independent" responses toward the auditory tonal deviants (Luo et al., 2006), although attention may modulate the strength of MMN observed (see Sussman, 2007, for discussion). In active oddball, participants are asked to respond overtly whenever a deviant is heard. Attention is thus required and participants can make use of the various cues available to improve task performance. This may encourage a deeper level of processing for the auditory stimuli. Results from the two experiments would reflect tonal processing in highly similar procedures that differ in the depth of lexical tone processing, which could be linked to the early and late stages of the two-stage model.

Two aspects of stimulus property were also manipulated. First, following Ren et al. (2009), we compared responses toward syllables and hums. Syllables are real Chinese words carrying meanings, while hums are non-linguistic. According to the two-stage model (Luo et al., 2006), initial tonal processing is based on general auditory mechanisms, such that syllables and hums should be processed identically. Ren et al. (2009) have reported evidence for this prediction by showing identical MMNs in the two conditions.[‡] However, they did not examine the contrast between syllables and hums at the later stage, where differences should begin to emerge according to the model. We tested this prediction in Experiment 2 with the active oddball task. Second, Tsang et al. (2011) showed that tonal features (f0 direction and f0 height deviation) affected the strength of MMN, which is consistent with the prediction that early tonal processing is sensitive to basic acoustic factors. Moreover, Francis et al. (2003) showed that Cantonese contour tones are perceived more categorically than level tones, which might influence the strength of MMN (Xi et al., 2010). However, it is still not clear how tonal features affect the later stage of tonal processing. In this study, we manipulated the tonal features as in Tsang et al. to see whether they modulate the contrast between stimuli (syllables and hums) and the contrast between tasks (passive and active oddball).

EXPERIMENT 1: PASSIVE ODDBALL PARADIGM

Experiment 1 examined the processing of Cantonese lexical tones with the passive oddball paradigm. We manipulated three independent variables: f0 direction (level vs. contour), f0 height deviation (large vs. small),

[‡] Pulvermüller et al. (2004) showed that MMN was larger for words than pseudowords, indicating that MMN is modulated by lexical status. However, this lexicality effect is typically interpreted as evidence that MMN depend not just on temporally formed memory trace but is also sensitive to long-term memory of words. This does not alter the proposal that passive oddball reflects shallower processing than the active version.