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Online processing of tone and intonation in Mandarin: Evidence from ERPs

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ABSTRACT

Event-related potentials (ERPs) were used to investigate the online processing of tone and intonation in Mandarin at the attentive stage. We examined the behavioral and electrophysiological responses of native Mandarin listeners to Mandarin sentences, which contrast in final tones (rising Tone2 or falling Tone4) and intonations (Question or Statement). A clear P300 effect was observed for question-statement contrast in sentences ending with Tone4, but no ERP effect was found for question-statement contrast in sentences ending with Tone2. Our results provide ERP evidence for the interaction of tone and intonation in Mandarin, confirming the findings with behavioral metalinguistic data that native Mandarin listeners can distinguish between question intonation and statement intonation when the intonation is associated with a final Tone4, but fail to do so when the intonation is associated with a final Tone2. Our study extended the understanding of online processing of tone and intonation (1) from the pre-attentive stage to the attentive stage and (2) within a larger domain (i.e. multi-word utterances) than a single word utterance.

1. Introduction

In spoken language processing, different aspects of linguistic information are involved, such as lexical, semantic, syntactic and prosodic information (Friederici, 2002; Isel et al., 2005). Among these aspects, prosodic information, especially pitch information, has been shown to be indispensible for spoken language processing in tonal languages such as Mandarin (e.g., Li et al., 2011). Tone and intonation have been considered the two most significant prosodic features of Mandarin speech (Tseng and Su, 2014). At the lexical level, F0 is employed to differentiate the four lexical tones (Tone1 - high-level, Tone2 - mid-rising, Tone3 - low-dipping and Tone4 - high-falling), which contrast lexical meanings (Cutler and Chen, 1997; Yip, 2002). At the sentential level, F0 is also used to convey post-lexical information, for example, intonation types (e.g., question intonation, statement intonation) (Ladd, 2008). Although other acoustic correlates (such as duration, intensity and phonation) have also been shown to contribute to cue tonal and intonational contrasts (Garellek et al., 2013; Hu, 1987; Shi, 1980; Xu, 2009; Yu and Lam, 2014), F0 has been identified as the primary acoustic correlate of both tone and intonation in Mandarin (Ho, 1977; Shen, 1985; Wu, 1982; Xu and Wang, 2001; Xu, 2004). It may therefore not be surprising that tone and intonation interact with each other both in production and perception.

The interaction of tone and intonation in Mandarin has aroused great interests among researchers, and several models or theories have been put forward based mainly on acoustic data since the first studies on the topic by Chao (Chao, 1929, 1933). Of these acoustic studies, a general belief is that question intonation has higher F0 than statement intonation (Cao, 2004; Gårding, 1987; Shen, 1989; Wu, 1996). However, there is controversy about the temporal scope of such higher F0 in question intonation. Two alternative views have been established. One holds that there is an overall F0 rising of sentences in questions compared to statements (Ho, 1977; Shen, 1989; Yuan, 2011). The other claims that the F0 difference between questions and statements is more pronounced towards the end of the sentences (Kratochvil, 1998; Liu and Xu, 2005; Xu, 2005; Peng et al., 2005).

Different from the above acoustic studies, Liang and Van Heuven (2007) conducted intonation perception experiments with a seven-syllable-sentence containing merely high-level tone syllables. They manipulated both the overall pitch level of the sentence and the pitch level of the final tone. Results showed that manipulating the final rise has a much stronger effect on the perception of intonation type than manipulation of the overall pitch level, indicating that the F0 of the final tone is more important than that of the whole sentence for intonation perception.

Not unique to Mandarin, the final rise has been shown to be a language-universal perceptual cue for question intonation (Gussenhoven and Chen, 2000). In a made-up language, Gussenhoven and Chen (2000) tested the perceptual cues for question

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intonation across three different language groups. All listeners tended to take the higher peak, the later peak and the higher end rise as cues for question intonation perception. In Cantonese, another representative language other than Mandarin within the Sinitic language family, Ma et al. (2011) also found that the perception of questions and statements relies primarily on the F0 characteristics of the final syllables.

Apart from studies on the temporal domain of perceptual cues of intonation, there has also been research, though regretfully little, on the effect of intonation on tone perception and vice versa. Connell et al. (1983) ran a tone perception experiment in Mandarin and found that intonation-induced F0 has little effect on tone perception. Tone identity maintains in question intonation. With regard to the effect of tone on intonation perception, Yuan (2011) found that in Mandarin, questions ending with Tone4 (falling tone) were easier to identify than questions ending with Tone2 (rising tone). Three mechanisms were proposed for question intonation: an overall higher phrase curve, higher strengths of sentence-final tones and a tone-dependent mechanism. The tone-dependent mechanism conflicts with the strength mechanism on the final Tone2, possibly accounting for the difficulty of question identification in sentences ending with Tone2. In sentences ending with Tone4, the tone-dependent mechanism flattens the falling slope of the final falling, making question intonation perceptually more salient for falling tone (Yuan, 2006).

Unlike in Mandarin, the intonation-induced F0 affects tone perception in Cantonese. Low tones (21, 23, 22) (tone values in 5-point scale notation, each tone is described by the initial and the end point of the pitch level) were misperceived as the mid-rising tone (25) at the final positions of questions (Fok-Chan, 1974; Kung et al., 2014; Ma et al., 2011). This is probably because with a rising tail superimposed on all tone contours by question intonation (Ma et al., 2006), the F0 contour of the low tones in questions resembles that of a mid-rising tone in questions. As for the effect of tone on intonation perception, native listeners were least accurate of all the six tones in Cantonese in distinguishing statements and questions for sentences ending with Tone 25 (Ma et al., 2011), suggesting that listeners confused the rising contour of Tone 25 with the final rise of question intonation.

Taken together, potential conflicts exist between tone and intonation in Mandarin and Cantonese, causing processing difficulties at the behavioral level. However, the underlying neural mechanisms leading to the eventual behavioral decisions are not yet clear. To shed light on this issue, research is needed to investigate the online processing of tone and intonation.

In recent years, a number of neurophysiological studies in regard to pitch processing have emerged, mainly with lesion, dichotic listening and functional neuroimaging techniques (Gandour et al., 1992; Klein et al., 2001; Van Lancker and Fromkin, 1973; Wang et al., 2003). However, due to the low temporal resolution of these techniques, event-related potentials (ERPs), a high temporal resolution measure was introduced to pitch processing, offering more precise temporal information of online processing.

The majority of ERP studies relevant to pitch processing focus on the neural mechanisms of tone processing at the pre-attentive stage, where participants are directed to watch a silent movie or read a book and to ignore the auditory input (Fritz et al., 2007). In these studies, the ERP component of interest is the Mismatch-Negativity (MMN), an indicator of acoustic change detection (Näätänen, 2001; Pulvermüller and Shtyrov, 2006). Only two studies examined the online processing of both tone and intonation in Mandarin, to our knowledge. Ren et al., (2009) constructed an oddball sequence. A word with lexical Tone4 (i.e., /gai4/[1]), uttered with statement intonation was presented as the standard stimulus, and /gai4/ with question intonation was presented as the deviant stimulus to native Mandarin listeners. Their results showed a clear MMN effect when subtracting the waveform of the standard from that of the deviant. In another study, Ren et al. (2013) adopted a three-stimuli oddball paradigm. The standard stimulus was /lai2/ with statement intonation. The deviant stimuli included an intonation deviant (/lai2/ with question intonation) and a lexical tone deviant (/lai4/ with statement intonation). Results showed an MMN for the tone deviant but not for the intonation deviant. As the MMN is linked to higher order perceptual processes underlying stimulus discrimination (Pulvermüller and Shtyrov, 2006), the above two studies suggest that at the pre-attentive stage, native listeners can tease apart question intonation from statement intonation when the intonation is combined with Tone4, but they are not able to tease apart the two types of intonation when the intonation is combined with Tone2, just as what Yuan (2011) has reported with behavioral perceptual judgment data. This correspondence of the online MMN results with the offline behavioral results validates the initial ERP evidence of the interaction of tone and intonation in Mandarin.

In addition to Mandarin, ERP evidence of online interplay of tone and intonation is also revealed in Cantonese (Kung et al., 2014). In this study, Cantonese participants were asked to perform a lexical-identification task, i.e., choosing the right word they heard from six Cantonese words on the screen in the form of Chinese characters, and the six words were tonal sextuplets of the critical word. ERP analyses revealed a P600 effect for low tone in questions relative to low tone in statements. The P600 effect was explained as an indicator of reanalysis, in the presence of a strong conflict of two competing representations activated in questions ending with low tones. The two representations are a lexical representation with a low tone on the one hand and a lexical representation with a high rising tone on the other. Special attention should be paid to the fact that Kung et al. (2014) found a P600 effect in the semantically neutral sentence context. In their subsequent study, when introducing a highly constraining semantic context to the target words, the P600 disappeared, suggesting that semantic context plays a role in resolving the online conflict between intonation and tone.

Several remaining issues may be noticed given the above ERP studies on the processing of tone and intonation. First, the MMN studies of Mandarin restricted their attention to the interaction of

Table 1
An example of the experiment design.

Conditions		Examples				
Tone	Intonation					
Tone2	Statement	Characters	她	刚刚	说	**X**(财)。
		Pinyin	ta1	gang1gang1	shuo1	**cai2**
		IPA	[t^hA1]	[kaŋ1 kaŋ1]	[$ʂ^huo1$]	**[ts^hai2]**
		English	She	just	said	**money.**
Tone2	Question	Characters	她	刚刚	说	**X**(财)**?**
		Pinyin	ta1	gang1gang1	shuo1	**cai2**
		IPA	[t^hA1]	[kaŋ1 kaŋ1]	[$ʂ^huo1$]	**[ts^hai2]**
		English	She	just	said	**money?**
Tone4	Statement	Characters	她	刚刚	说	**X**(菜)。
		Pinyin	ta1	gang1gang1	shuo1	**cai4**
		IPA	[t^hA1]	[kaŋ1 kaŋ1]	[$ʂ^huo1$]	**[ts^hai4]**
		English	She	just	said	**vegetable.**
Tone4	Question	Characters	她	刚刚	说	**X**(菜)**?**
		Pinyin	ta1	gang1gang1	shuo1	**cai4**
		IPA	[t^hA1]	[kaŋ1 kaŋ1]	[$ʂ^huo1$]	**[ts^hai4]**
		English	She	just	said	**vegetable?**

Note. The critical syllables are in bold.

[1] The number following the letters in Mandarin Pinyin represents Mandarin