

## Do Mandarin listeners use post-stop F0 to distinguish phonological voicing?

Yuting Guo, Harim Kwon

Consonant-induced F0 perturbation in the post-stop vowel has been observed in Mandarin speakers' production of phonologically voiceless and voiced stops (e.g., Xu & Xu 2003, Luo 2018). However, contradictory findings have been reported on the direction of the F0 perturbation, with its duration being shorter than those in non-tonal languages. This is presumably because F0 is the primary cue for lexical tone in Mandarin. Consequently, the role that F0 plays in stop contrast perception in tonal languages is less clear while F0 serves as a secondary cue for stop laryngeal contrast in non-tonal languages such as English (e.g., Whalen et al. 1993). When F0 perturbation is limited in its duration and potentially inconsistent in its direction, do Mandarin native listeners use the F0 information as a cue for consonant voicing contrast? Moreover, can they extract consonantal information from F0 when they listen to their non-tonal second language (L2) in which F0 functions differently? To answer these questions, this study examines Mandarin listeners' perception of phonological /t-/d/ contrast in Mandarin and English, focusing on how VOT and post-stop F0 influence their perceptual judgments.

Twenty-five Mandarin native speakers who speak English as L2 participated in two forced-choice identification experiments, one in Mandarin and the other in English, on two separate days. A Mandarin native speaker produced the Mandarin base tokens with four lexical tones (i.e., /tū/, /tú/, /tǔ/, and /tù/). An English native speaker produced the English base tokens, *tie* /taɪ/ and *too* /tu/. Each base token was then manipulated to create 49 syllables with the initial /t/ co-varying in its VOT and post-stop F0, by fully crossing 7 steps of F0 and VOT. The participants heard one syllable at a time, and were instructed to identify the syllable they heard by selecting one of the two choices provided on screen. The two choices were two Chinese characters constituting the voiceless and voiced pairs (e.g., 突 /tū/ vs. 督 /dū/) in the Mandarin experiment and English word pairs (e.g., *too* /tu/ vs. *do* /du/) in the English experiment.

Listeners' responses were statistically analyzed using generalized linear mixed models. In Mandarin experiment, the listeners' /t/ vs. /d/ responses were significantly influenced by VOT ( $p < 0.001$ ), post-stop F0 ( $p < 0.01$ ) and lexical tone ( $p < 0.001$ ). Stimuli with shorter VOT, those with lower post-stop F0, and those starting at a lower pitch range (tones 2 and 3, as opposed to tones 1 and 4) elicited more /d/ responses (Figure 1). None of the interactions was significant.

In English experiment, listeners were more likely to choose /d/ when VOT was shorter ( $p < 0.001$ ), when post-stop F0 was lower ( $p < 0.001$ ), and the vowel was /u/ than /aɪ/ ( $p < 0.001$ ). See Figure 2. Unlike in Mandarin, the interaction between VOT and vowel was significant ( $p < 0.01$ ): the vowel effect was significant when VOT was at lower range. As VOT increased, the responses were mostly /t/ regardless of the vowel in the stimuli. The vowel effect indicates that the listeners more frequently interpreted stops with ambiguous VOT as voiced in the context of /u/—a context that would have higher intrinsic f0 in natural speech (e.g., Whalen & Levitt 1995)—than in the context of /aɪ/. The listeners arguably attributed the post-stop F0 to the intrinsic F0 of the vowel rather than to the consonant perturbation effect. The interaction between F0 and vowel was not significant.

The current findings suggest that Mandarin listeners use post-stop F0 as a cue for the preceding stop's laryngeal contrast in both their native language and in their L2 English. They associate higher F0 with phonologically voiceless stops and lower F0 with voiced ones despite the conflicting findings on F0 perturbation in their native production. In addition, the perception of phonological voicing was mediated by lexical tones in Mandarin, and the vowel contexts in English.

**References:**

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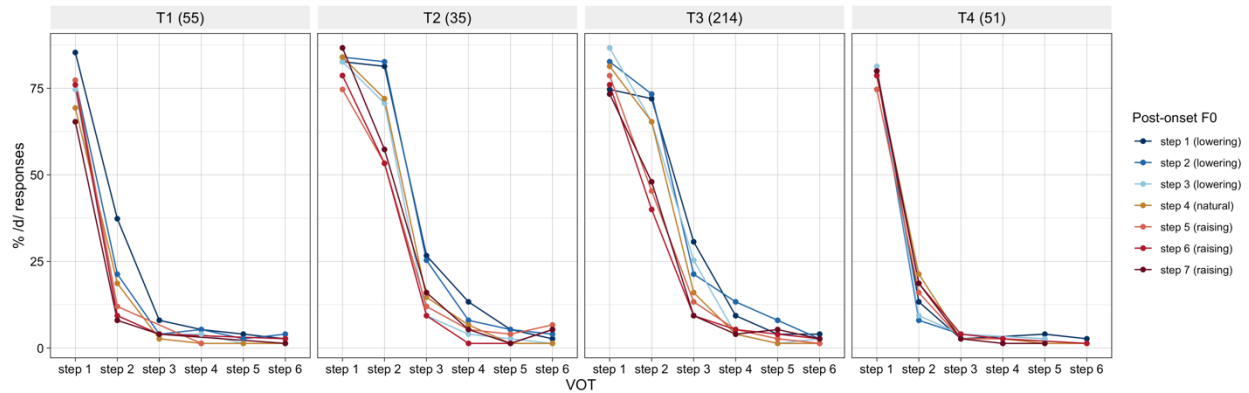


Figure 1. Percentage of /d/ responses by native Mandarin speakers in Mandarin experiment

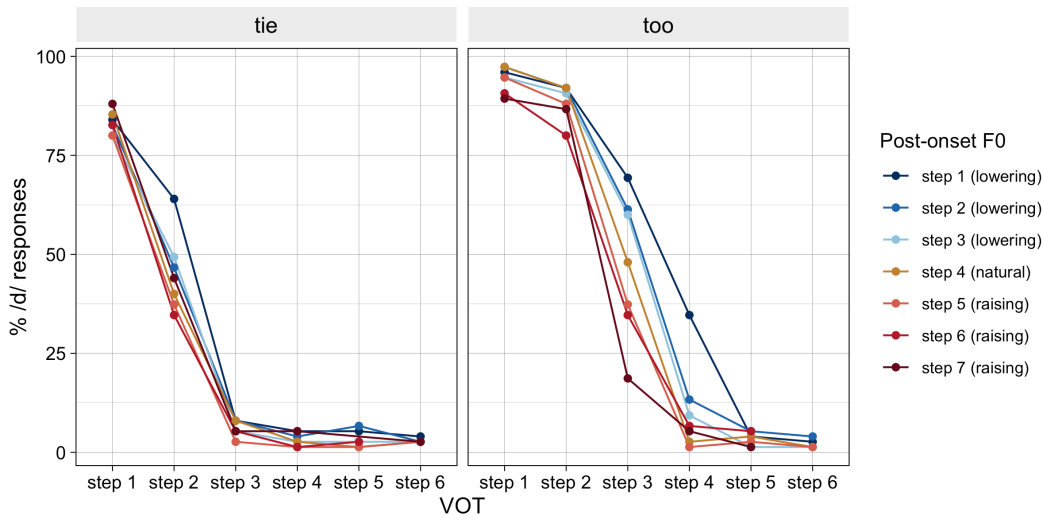


Figure 2. Percentage of /d/ responses by native Mandarin speakers in English experiment