Neural Representation of Lexical Tones in Cantonese

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Lexical tones are suprasegmental phonemes that distinguish meaning of words, and thus critical in oral communications in tonal languages like Cantonese, Mandarin, and Thai. While segmental aspects of phonetic feature encoding in human cortex have been well examined, investigation on suprasegmental aspects is rare. Linguists describe lexical tones in a two-dimension framework: pitch height [mean fundamental frequency (F0)] and pitch slope (gradient of F0 trajectories). Compared to Mandarin tone processing which relies primarily on slope information, Cantonese tone processing has a higher demand on processing pitch height. In Cantonese, there are three level tones with similar slope but varying heights and tones with similar height but different slopes, providing an ideal system for investigating the neural basis of lexical tone processing. In this study, we asked participants to listen to Cantonese tonal syllables in the MRI environment. Their brain activations were analysed to identify brain regions representing general tone processing, and pitch height and slope processing specifically.

42 native Cantonese speakers [age (mean±SD) = 23.2±3.9, 20 females, all right-handed] participated in this study. They performed three tasks: a passive listening task (PAS), a silent repetition task (REP), and a word identification task (WID) where participants identified corresponding character to heard tonal syllables. The behavioural results showed that participants had a high identification rate (84.4±9.9%), indicating successful identification.

The brain activation was recorded using a sparse sampling method (TR = 1500 ms including 700 ms silence, TE = 38 ms, TA = 3:02 min), with which the sound stimuli were always presented in the quiet periods of scanning. Participants' structural T1 images (TR = 2500 ms, TE = 2.16ms, TA = 3:22 min, voxel size = 1 mm^3) were also obtained. The MRI data were preprocessed using SPM12 with a standard pipeline. A univariate analysis identified bilateral temporal-frontal activation across tasks, which replicated previous findings and confirmed validity of the current design.

Whole-brain searchlight multi-variate pattern classification (MVPC) of tone categories was performed with a leave-one-task-out validation procedure in The Decoding Toolbox. This searchlight MVPC identified a bilateral network sensitive to tone categories in general, consisting of bilateral STG, left inferior parietal lobule (LIPL), left inferior frontal gyrus (LIFG), right middle frontal gyrus (RMFG), right superior frontal gyrus (RSFG), and bilateral lingual gyrus (BiLG). These brain regions served as ROIs in the following representational similarity analysis (RSA) to identify brain regions sensitive to pitch height and slope. Dissimilarity matrices (DMs) were built in the acoustic and neural domain on tonal syllable level. Three acoustic DMs were generated by considering the distances among F0 features. Neural DMs were built for each ROI on subject-level by considering differences among t values. Model fit was defined as the (partial) correlation of the acoustic DMs with the neural DMs. We found bilateral STG, LIPL, BiLG showed significant model fit with tone height model, while only LIPL with pitch slope model. LIFG, RMFG, and BiLG had a high model fit with the vector model while the latter two ROIs contributed to tone representation beyond pitch height and slope.

Compared with previous research on Mandarin tones, our results suggested that Cantonese tone representation consists of extended brain regions, with bilateral STG dedicated to pitch height processing and several frontal regions served a role in holistic tone process. This might be driven by the tone complexity, especially the demand on processing pitch height.