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Right hemisphere advantage in processing Cantonese level and contour tones: Evidence from dichotic listening

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HIGHLIGHTS

- Cantonese and Mandarin lexical tones show distinct hemisphere advantages.
- Acoustic properties of Cantonese tones determine their lateralization pattern.
- Lacking phonetic training limits the role of left hemisphere in Cantonese processing.

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ABSTRACT

The brain lateralization pattern of Cantonese tonal processing was examined with the dichotic listening (DL) paradigm. Three factors were manipulated systematically in the study. First, the processing of level tones was compared with that of contour tones. Second, the influence of a linguistic context in tonal processing was studied by contrasting the patterns of brain lateralization for real syllables, pseudo-syllables, and hums. Finally, the discrimination and the identification tasks were used to test how processing depth might modulate the results obtained. A right hemisphere advantage (RHA) was obtained regardless of tone type, stimulus type, and task. In addition, the performance on level tones was in general better than that on contour tones. These findings suggest that Cantonese speakers are highly sensitive to the acoustic features of lexical tones, which supports the acoustic view about tonal processing.

1. Introduction

In tonal languages, such as Chinese, Thai, and Vietnamese, lexical items are differentiated not just by phonemic contrasts (e.g., "cat" vs. "cap") but also by variations in lexical tone, which is acoustically determined by the fundamental frequency (f0) of speech sound. For instance, in Mandarin Chinese, the syllable /ma/ refers to "mother" when pronounced in a high level tone or "horse" in a low dipping tone. Previous studies have shown that lexical tone plays an important role in spoken word recognition [3,6,23,28]. Therefore, to better understand speech perception in tonal languages, it is important to investigate the mechanisms involved in processing lexical tones [4,29]. One issue that has generated intense interest in the literature concerns whether the processing of lexical tones relies on some general neural circuits for processing fundamental frequency (i.e., the acoustic view), involves a language-specific module (i.e., the functional view), or takes into account both acoustic and functional properties at different processing stages [10,17].

The acoustic and the functional views make opposite predictions about the brain lateralization pattern during the processing of lexical tones. According to the acoustic hypothesis [20,29], acoustic properties of the incoming signal determine which brain areas are engaged. Given that the right hemisphere (RH) is responsible for processing f0-related information, the acoustic hypothesis predicts that lexical tones are processed primarily in the RH. In contrast, the functional hypothesis assumes that the functional role of the incoming signal is more important in determining the brain areas involved. Therefore, lexical tones should be processed mainly by the left hemisphere (LH), which is usually regarded as the "language brain" in right-handed people [15,16].

Both the acoustic and the functional hypotheses have received empirical support [27,30]. For instance, the acoustic account was supported in an ERP experiment by Luo et al. [17], who showed that the pre-attentive sensitivity to changes in Mandarin tone, as indicated by mismatch negativity (MMN), was stronger in the RH. Ren

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et al. [21] arrived at the same conclusion using ERP source localization. However, the functional account was supported by several dichotic listening (DL) experiments [25,26], in which participants could more accurately report Mandarin tones presented to their right ear (i.e., a left-hemisphere advantage, LHA). The same LHA was also observed in the perception of Thai [13,14] and Norwegian tones [18]. To reconcile these discrepant results, researchers proposed that lexical tone perception is mediated by both hemispheres. The RH may play a more important role at the early stage for complex-sound analysis, while the LH becomes more dominant at the later stage for linguistic processing [10,11,30].

Note that one possible source of the discrepant results is the stimulus manipulation. In previous studies, researchers usually considered processing lexical tones as a single and unified dimension of speech activity, ignoring the fact that different lexical tones are themselves characterized by different acoustic features. Indeed, some early studies [7–9] have demonstrated that the perception of lexical tones was sensitive to two properties of f0: Its height (i.e., the average "level" of f0) and the direction of f0 change over time (i.e., stable or changing). These properties can be clearly illustrated by the six tones in Cantonese. Specifically, the three level tones (i.e., 1, 3, and 6) have a stable tone direction and differ only in pitch height. However, both tones 2 and 5 have a rising direction and a similar initial level of f0, but differ in f0 level toward the end of the carrying syllable (i.e., the f0 level of tone 2 rises more). Finally, although tone 4 has a similar level of initial pitch height as tones 2, 5, and 6, it has a falling direction.

The psychological validity of pitch height and pitch direction in Cantonese tonal processing has received further support in subsequent research. For instance, Khouw and Ciocca [12] showed that pitch direction was important in discriminating contour tones (i.e., 2, 4, and 5) from level tones (i.e., 1, 3, and 6) as well as among the contour tones themselves, while pitch height became more relevant in discriminating among the level tones. Furthermore, differences in the processing of pitch height and pitch direction emerged even at the pre-attentive stage of processing. As shown in an ERP experiment adopting the passive oddball paradigm [24], deviations in pitch height and direction elicited two different ERP components, namely MMN and P3a, respectively. Taken together, both behavioral and ERP data appear to suggest that different types of lexical tones may be processed differently.

In the present study, we explored whether the level and the contour Cantonese tones lead to different patterns of brain lateralization, which could test the effect of acoustic features on tone processing. We also examined whether a linguistic context would moderate the lateralization pattern. The lexical status of the stimulus was manipulated such that the lateralization pattern of real Cantonese syllables was compared against that of pseudo-syllables (combinations of phonemes without corresponding lexical entries) and hums (non-linguistic items). By analyzing the interaction between tonal type and stimulus type, we intended to examine the more comprehensive model [10,17].

The DL technique was adopted to determine the pattern of lateralization in tonal processing [2,11,13,14,25,26]. Participants were presented with different auditory signals simultaneously to each of their ears and were instructed to discriminate or identify the stimuli they heard. Note that the discrimination and identification tasks involve linguistic processing to different extents. Specifically, lexical access is required for the identification task, making any linguistic influence relatively more prominent in this specific task. In contrast, the discrimination task could in principle be completed based solely on perceptual processing. Thus, the potential impact of a linguistic context might be relatively small in the discrimination task. In other words, we also examined possible effects of task demand on tonal processing by comparing the results obtained in the discrimination and identification tasks.

Table 1
The four sets of Cantonese syllables chosen for the experiments.

Tone	Set 1 (/si/)	Set 2 (/fu/)	Set 3 (/se/)	Set 4 (/yi/)
1	詩 – "poem"	夫 – "husband"	些 – "some"	姨 – "aunt"
2	史 – "history"	父 – "father"	寫 – "write"	椅 – "chair"
3	試 – "try"	褲 – "trousers"	瀉 – "diarrhea"	意 – "meaning"
4	時 – "time"	符 – "symbol"	蛇 – "snake"	兒 – "son"
5	市 – "city"	婦 – "woman"	社 – "society"	耳 – "ear"
6	氏 – "surname"	負 – "negative"	射 – "shoot"	二 – "two"

Note: Phonologically, each spoken item can be coded as "syllable + tone". For example, 詩 (poem) is coded as /si1/. Only one example (and its translation) was given for each combination, although there are homophones for some combinations. The number of homophones was balanced across the six tones.

2. Materials and methods

2.1. Participants

Twenty-seven (13 males; age = 18–24) and 34 (13 males; age = 18–23) undergraduate students at The Chinese University of Hong Kong were recruited for the discrimination and the identification tasks, respectively. All of them were native Cantonese speakers and were right-handed as indicated by the Edinburgh inventory of handedness [19]. None of them reported having hearing impairments or formal musical trainings for over three years. An audiometric test was conducted to ensure that the sensitivity of the two ears did not differ. All participants provided informed consent according to the regulations of the Department of Psychology.

2.2. Materials

Materials included syllables, pseudo-syllables, and hums. Four Cantonese syllables (/si/, /fu/, /yi/, and /se/) were chosen, each of which can be paired with the six tones, resulting in six distinct lexical items (Table 1). The frequency and number of homophones were controlled across the six tone types ($Fs \leqq 1.67$ and $ps \geqq .43$; [22]). Four sets of pseudo-syllables (/bi/, /bu/, /di/, and /du/) were also prepared. These pseudo-syllables are pronounceable but do not correspond to existing lexical items. The syllables and pseudo-syllables were recorded on a DAT tape by a phonetically trained female native Cantonese speaker. The recording was then digitalized at a sampling rate of 44.1 kHz. The resulting stimuli were edited for normalization of duration (400 ms, including the 15 ms rise and fall ramps) and peak intensity (60 dB). Finally, using Praat [1], hums (non-linguistic materials) were synthesized from the real syllables by removing the segmental information while retaining the f0 pattern.

2.3. Procedure

We followed the procedure in Brancucci et al. [2] for the discrimination task. In each trial, participants were presented with two dichotic pairs, the target-mask pair and the probe-mask pair, sequentially. The target and probe were presented to the same ear, which worked as the testing ear. Participants were asked to ignore the mask and pay full attention to the experimental item (i.e., syllable, pseudo-syllable, or hum) in the testing ear. The onset interval of two dichotic pairs was one second and participants had to judge whether the probe was identical to the target or not by pressing corresponding keys on a response box. Reaction times (RTs) and accuracies were measured from the onset of the probe. There was a one-second interval between trials. If participants failed to produce any response within two seconds, the next trial started automatically.

Syllables, pseudo-syllables, and hums were tested in different sessions. In each session, level and contour tones were presented in