T. Christina Zhao and Patricia K. Kuhl: JASA Express Letters [http://dx.doi.org/10.1121/1.4927632] Published Online 7 August 2015

Higher-level linguistic categories dominate lower-level acoustics in lexical tone processing

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Abstract: Native tonal-language speakers exhibit reduced sensitivity to lexical tone differences within, compared to across, categories (higher-level linguistic category influence). Yet, sensitivity is enhanced among musically trained, non-tonal-language-speaking individuals (lower-level acoustics processing influence). The current study investigated the relative contribution of higher- and lower-level influences when both are present. Seventeen Mandarin musicians completed music pitch and lexical tone discrimination tasks. Similar to English musicians [Zhao and Kuhl (2015). J. Acoust. Soc. Am. **137**(3), 1452–1463], Mandarin musicians' overall sensitivity to lexical tone differences was associated with music pitch score, suggesting lower-level contributions. However, the musician's sensitivities to lexical tone pairs along a continuum were similar to Mandarin non-musicians, reflecting dominant higher-level influences.

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Date Received: May 12, 2015 **Date Accepted:** July 2, 2015

1. Introduction

Speech perception is influenced by processing and decision-making at multiple levels. The listener must accurately process the acoustic information in the speech signal (lower-level acoustic processing influence) and assign these highly variable speech sounds efficiently and consistently to phonemic categories (higher-level linguistic category influence). Previous research has demonstrated that listeners' performance in speech perception tasks is influenced by the amount of experience they have with each of the processing strategies (i.e., using higher or lower-level information more) (Chandrasekaran *et al.*, 2009). Here, we use lexical tone processing as a tool to examine the performance of listeners who have had extensive experience in both processing strategies, evaluating the relative influence of the two strategies.

Lexical tones are contrastive pitch contour patterns at the word level. That is, a small difference in the pitch contour can lead to change of word meaning. Therefore, native speakers of a tonal language have extensive experience in using a higher-level linguistic category information to categorize highly variable pitch contours. This higher-level influence is expressed as reduced sensitivity to pitch contour differences within a lexical tone category compared to across-category sensitivity. A well-established experimental approach involves creating a lexical tone continuum by gradually varying the pitch contours from one lexical tone category to another and measuring listeners' sensitivity to pairs of tones along the continuum. It has been demonstrated repeatedly that native tonal language speakers have reduced sensitivity for pairs of lexical tones that fall within the same tone category (Fig. 1) (Halle *et al.*, 2004; Xu *et al.*, 2006; Zhao and Kuhl, 2015).

On the other hand, non-tonal language speaking individuals with extensive music training early in life exhibit enhanced sensitivity to pitch differences, not only in music, but also in speech, reflecting stronger lower-level acoustic processing influences. Such enhancement in pitch processing in speech has been observed for lexical tones in non-tonal language speakers, using both behavioral and electrophysiological measures (Fig. 1) (Alexander *et al.*, 2005; Chandrasekaran *et al.*, 2009; Wong *et al.*, 2007; Zhao and Kuhl, 2015).

Therefore, native Mandarin speakers with early music training can be considered to have extensive experience in both processing strategies, and their performance on lexical tone processing tasks can reveal the relative contribution of higher and lower-level influences. The current study provides new data from native Mandarin speaking musicians on both a music pitch discrimination task and a lexical tone discrimination task used in a previous study (Zhao and Kuhl, 2015), comparing their performance with data collected from native Mandarin speaking non-musicians (prominent

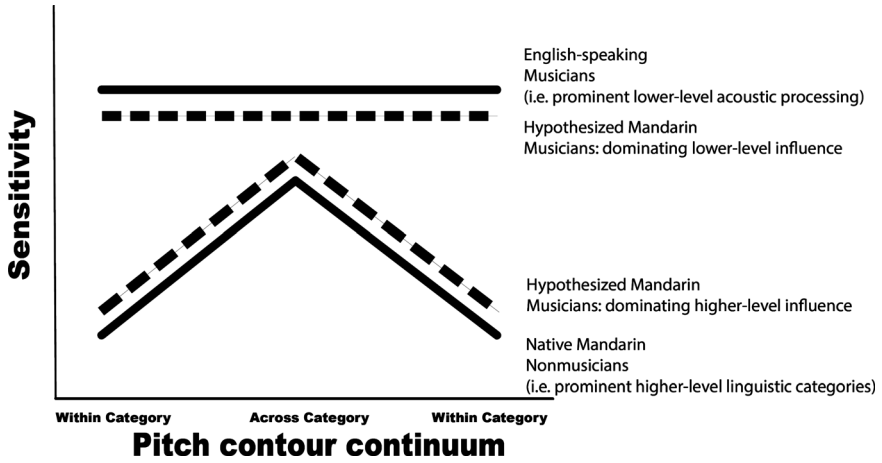

Fig. 1. Schematic of sensitivities for tone pairs along the continuum when listeners have had extensive experience with either lower-level or higher-level processing. The dashed lines indicate potential outcomes and interpretation for Mandarin musicians with extensive experience in both processing strategies.

higher-level influence) and English-speaking musicians (prominent lower-level influence) in that study. The hypothesized outcomes and interpretations are illustrated in Fig. 1. In a recent paper, Wu *et al.* (2015) compared the performance of Mandarin musicians and non-musicians, and reported that Mandarin musicians exhibited better sensitivity within phonemic categories than the non-musicians. The current study differs from their study in two important ways: (1) methodologically, a different tone continuum (tone 2–tone 3 instead of tone 1–tone 4) was adopted (see Zhao and Kuhl, 2015, for selection rationale). In addition, a speeded task was adopted in the current study instead of a self-paced task, minimizing the influence of working memory. (2) Data from a music pitch discrimination task in Mandarin Musicians and data from English musicians and Mandarin non-musicians using the same tasks allow a direct examination of higher and lower-level influences.

2. Method

2.1 Participants

Seventeen native Mandarin speakers participated in this study (5 males, age = 23.12 ± 4.10 yr). No participant reported any history of hearing, speech, or language difficulty. All participants had received at least 8 years of private music lessons that started before age of 10 years old (mean years of training = 15.18 ± 5.27 yr). These selection criteria for Mandarin musicians followed the same criteria for the English musicians in our previous study, while the Mandarin non-musicians received less than 2 years of private lessons that ended more than 5 years ago (Zhao and Kuhl, 2015). All procedures were approved by the Institution Review Board and all participants were compensated for their participation.

2.2 Tasks

All participants completed two tasks: a music pitch discrimination task and a lexical tone discrimination task. The music pitch discrimination task was the pitch sub-test of the Wing standardized test of musical intelligence (Wing, 1966) and performance on this task reflects the level of music pitch processing.

The lexical tone discrimination task measured listeners' sensitivity to lexical tones using an established T2-T3 continuum in which 9 lexical tone pitch contours varied from Tone 2 (rising tone) to Tone 3 (falling-rising tone) (Fig. 2). Participants were instructed to judge whether two vowel syllables were identical or different in an AX discrimination task. The two vowel syllables (Stimuli A and X), were otherwise identical, and carried lexical tone contours that were either 2 steps apart on the continuum ("different" pairs, e.g., 1-3, 3-1) or the same ("identical" pairs, e.g., 1-1, 3-3). In each trial, a 250 ms fixation point was presented on the computer screen to signal the start of a trial. Stimuli A and X were then presented sequentially with an inter-stimulus interval (ISI) of 300 ms. Participants were required to respond on the computer keyboard within 500 ms. Each participant was randomly assigned to one of the three vowel syllables that carried the lexical tone contours to minimize syllable effects (/ɣ/, /u/, /y/).

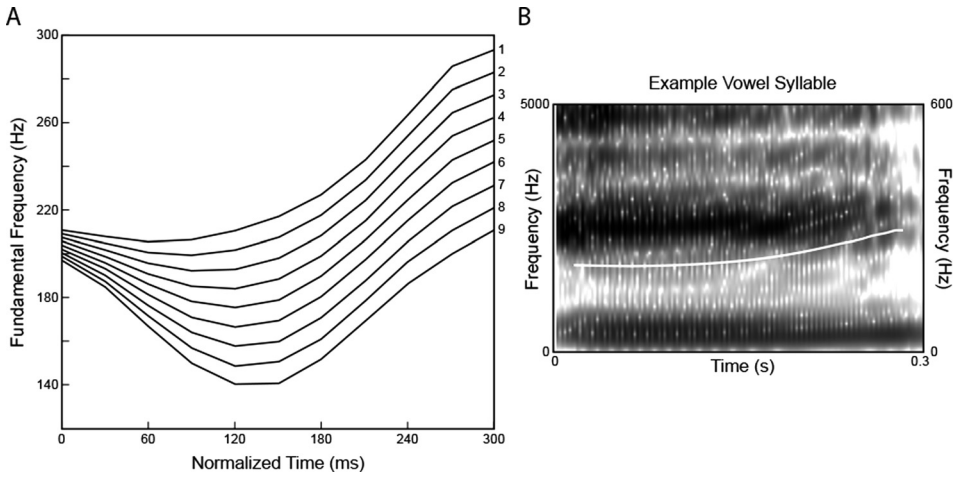

Fig. 2. (A) The nine-step F0 contour continuum from T2 (contour 1) T3 (contour 9), previously used in the Zhao and Kuhl (2015) study. (B) An example of the spectrogram of a vowel syllable with one of the tone contours.

3. Results

For the music discrimination task, percent correct was calculated as the dependent measure and data from Mandarin musicians were compared to Mandarin non-musicians and English musicians using a one-way analysis of variance (ANOVA) model, with Bonferroni *post hoc* tests (Table 1). Results revealed a significant main effect of group, $F\ (2,54) = 16.01$, $p < 0.001$, $\eta_p^2 = 0.37$. *Post hoc* tests indicate that Mandarin musicians and English musicians performed similarly (*ns*), and both groups performed significantly better than the Mandarin non-musicians ($p < 0.001$), thus confirming the enhanced music pitch processing in Mandarin musicians.

For the lexical tone discrimination task, two measures were calculated for each participant to characterize their performance: the overall sensitivity across the whole continuum (hereafter: overall sensitivity) and sensitivity for each tone pair along the continuum (hereafter: within-pair sensitivity). Sensitivity was calculated as the *d'* value from percent correct [*p*(*c*)] (Macmillan and Creelman, 2008). A response was counted as correct when the participant responded (1) "different" for "different" stimulus pairs, and (2) "same" for "identical" stimulus pairs.

First, we examined the predictive relation between the music pitch discrimination score and overall sensitivity in lexical tone discrimination in order to characterize the influence of a lower-level processing in the lexical tone discrimination task. Specifically, we examined (1) whether the overall lexical tone sensitivity can be predicted by the music pitch discrimination score in Mandarin musicians; (2) if so, whether this predictive relation between music pitch discrimination score and overall lexical tone sensitivity in Mandarin musicians is similar to that previously reported in Mandarin non-musicians and English musicians (Zhao and Kuhl, 2015). A multiple regression model was used to address these questions, using the music pitch discrimination score as the predictor and the overall lexical tone discrimination score as the outcome, incorporating the three groups as well as the interactions between the groups and the music pitch discrimination score into the model. Overall, the predictor and interaction terms explained 40.1% of the variance in the model [$F\ (5,51) = 6.84$, $p < 0.001$]. More specifically, in Mandarin musicians, the music pitch discrimination score was a significant predictor of the lexical tone discrimination score ($\beta = 0.138$, $p = 0.002$). The predictive relation in English musicians is not significantly different from Mandarin musicians ($\Delta\beta = -0.004$, ns), but the predictive relation in Mandarin non-musicians is significantly different from Mandarin musicians ($\Delta\beta = -0.138$, $p = 0.05$) [Fig. 3(A)].

Table 1. Music pitch discrimination scores from three groups (mean ± standard deviation).

	Mandarin musicians (n = 17)	English musicians (n = 20)	Mandarin non-musicians (n = 20)
Music pitch discrimination (Percent correct)	72.18% ± 18.14%	71.34% ± 11.01%	50.43% ± 12.28%

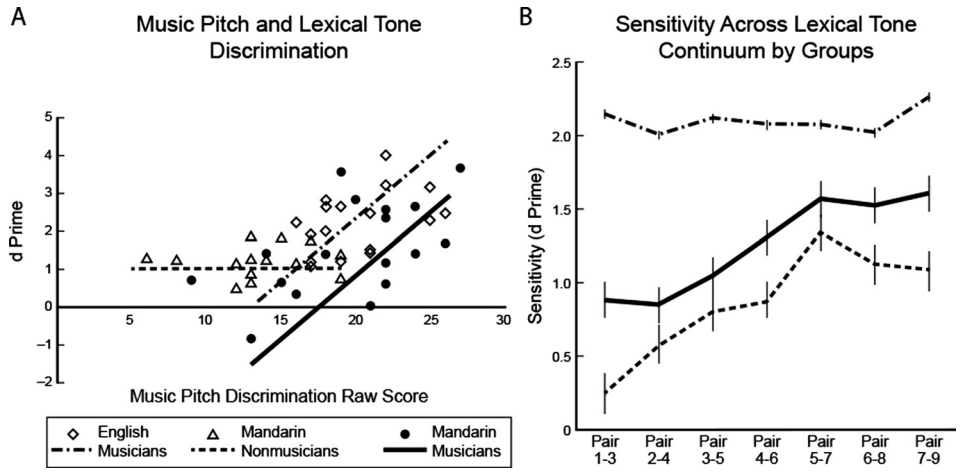

Fig. 3. (A) Scatterplot of music pitch discrimination score and overall sensitivity for lexical tones by group. The lines reflect the predictive relation for each group. In the Mandarin musician group and the English musician group, the music pitch discrimination score is a significant predictor of the overall lexical tone sensitivity, $y = -1.22 + 0.14x^*$, $y = -0.58 + 0.13x^*$. In the Mandarin non-musician group, the music pitch discrimination score does not predict the overall sensitivity of lexical tone, $y = 1$, reflecting independent processes. (B) Sensitivity to lexical tone pairs across the tone continuum for Mandarin musicians, Mandarin non-musicians and English musicians.

Then, we directly examined the within-pair sensitivity along the tone continuum in Mandarin musicians, in comparison to English musicians and Mandarin non-musicians [Fig. 3(B)]. Two specific statistical models were employed to address the influence of lower and higher level processing separately. To characterize the lower-level influence, we compared the within-pair sensitivities across the continuum between Mandarin musicians and Mandarin non-musicians addressing two specific questions: (1) Do Mandarin musicians exhibit overall higher sensitivity across the tone continuum compared to Mandarin non-musicians? (2) Do Mandarin musicians exhibit a different pattern of within-pair sensitivities across the continuum from the Mandarin non-musicians? A 2 (between subjects: group) $\times$ 7 (within subjects: tone pairs) ANOVA model was adopted to address these questions. Results showed that there was no significant main effect for group, $F(1,35) = 1.98$, ns, nor a significant interaction between group and tone pairs, $F(6,210) = 0.49$, ns. To characterize the higher-level influence, we compared the within-pair sensitivities across the continuum between Mandarin musicians and English musicians addressing the same questions, using the same statistical model. That is, (1) Do Mandarin musicians exhibit similar sensitivity across the tone continuum compared to English musicians? (2) Do Mandarin musicians exhibit a different pattern of within-pair sensitivities across the continuum from the English musicians? In this analysis, results showed a significant main effect for group [$F(1,35) = 7.11$, $p = 0.012$, $\eta_p^2 = 0.17$] as well as a significant interaction [$F(6,210) = 3.25$, $p = 0.004$, $\eta_p^2 = 0.08$].

4. Discussion

The current study investigated the relative contribution of lower-level and higher-level influences in processing phonemic information in speech, specifically using lexical tone processing as a tool. New experimental data from Mandarin musicians (individuals with extensive experience in using both lower-level and higher-level information for processing) was compared to existing data from Mandarin non-musicians (prominent higher-level) and English musicians (prominent lower-level) (Zhao and Kuhl, 2015). Mandarin musicians exhibited comparable performance in the music pitch discrimination task to the English musicians, and the music pitch discrimination score is a significant predictor of their overall sensitivity to lexical tone differences in both groups, suggesting that both groups may be relying on lower-level information processing in both tasks. The music discrimination score is significantly lower in the Mandarin non-musicians, as predicted; and there is no significant predictive relation between music discrimination and overall sensitivity to lexical tones in this group, suggesting the independent nature of music pitch processing and lexical tone processing in this group.

Yet, when examined directly and more closely, the lower-level influence exerted minimal effects on the within-pair lexical tone sensitivity across the continuum in Mandarin musicians; there was no difference between Mandarin musicians and non-musicians in either the overall sensitivity to lexical tones, or the pattern of within-pair sensitivities to tone pairs across the continuum. That is, both group exhibited reduced

sensitivity to within-category tone pairs in comparison to between-category pairs. The reduction in within-category sensitivity is more robust on the tone 2 end than the tone 3 end, which is consistent with the literature that the tone 3 category has more perceptual dimensions, such as voice quality (See more detailed discussion in Zhao and Kuhl, 2015).

The dominant effect of higher-level influence was further confirmed by the comparison of Mandarin musicians and English musicians. Specifically, Mandarin musicians exhibited significantly lower sensitivity to lexical tones overall than the English musicians (a significant main effect) and the pattern of within-pair sensitivity across the continuum are also different between the two groups (a significant interaction). That is, English musicians demonstrated a constant sensitivity across the continuum, while the Mandarin musicians demonstrated the reduced sensitivity within tone categories.

To summarize, new data from Mandarin musicians suggest stronger influences from a lower-level acoustic processing, compared to their non-musician counterparts in a lexical tone discrimination task, as indicated by the differential predictive relations between music pitch discrimination scores and overall sensitivity for lexical tones across groups. However, the influence of such differential weights in the lower-level processing appears minimal in discrimination of pairs of lexical tones, which was dominated by the influences of higher-level linguistic categories in both Mandarin groups: the pattern of within-pair sensitivity in Mandarin musicians was not significantly different from their non-musician counterparts but significantly different from English musicians.

Acknowledgments

This study was supported by the NSF LIFE Science of Learning Center Program grant to the UW LIFE Center (PK, PI: SMA-0835854) and the UW Institute for Learning and Brain Sciences Ready Mind Project.

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