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Laurianne Cabrera, Feng-Ming Tsao, Dan Gnansia, Josiane Bertoncini,  
Christian Lorenzi

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1                           **The role of spectro-temporal fine structure cues**  
2                           **in lexical-tone discrimination for French and Mandarin adult listeners**

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4                           **Laurianne Cabrera \***

5                           Laboratoire de Psychologie de la Perception, CNRS, Université Paris Descartes

6   45 rue des saints Pères, 75006 Paris, France

7                           **Feng-Ming Tsao**

8                           Department of Psychology, National Taiwan University

9   No.1, Sec. 4, Roosevelt Road, Taipei, 106, Taiwan

10                           **Dan Gnansia**

11                           Neurelec, 2720 Chemin de Saint-Bernard Porte, 06224, Vallauris, France

12                           **Josiane Bertoncini**

13                           Laboratoire de Psychologie de la Perception, CNRS, Université Paris Descartes

14   45 rue des saints Pères, 75006 Paris, France

15                           **Christian Lorenzi**

16   Laboratoire des systèmes perceptifs, CNRS,

17                           Institut d'Etude de la Cognition, Ecole normale supérieure, Paris Sciences et Lettres

18   29 rue d'Ulm, 75005 Paris, France

19  
20                           \* Corresponding author: Laboratoire de Psychologie de la Perception, CNRS-UMR 8158,  
21                           Université Paris Descartes, 45 rue des saints pères, 75006, Paris, France.

22                           Tel: +33 1 42 86 43 20

23                           E-mail address : [laurianne.cabrera@gmail.com](mailto:laurianne.cabrera@gmail.com)

24  
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26                           Running title: weight of modulation cues in lexical tones

## 1 **Abstract**

2 The importance of spectro-temporal modulation cues in conveying tonal information for  
3 lexical tones was assessed in native-Mandarin and native-French adult listeners using a  
4 lexical-tone discrimination task. The fundamental frequency (F0) of Thai tones was either  
5 degraded using an 8-band vocoder that reduced fine spectral details and frequency-modulation  
6 cues, or extracted and used to modulate the F0 of click trains. Mandarin listeners scored lower  
7 than French listeners in the discrimination of vocoded lexical tones. For click trains, Mandarin  
8 listeners outperformed French listeners. These preliminary results suggest that the perceptual  
9 weight of the fine spectro-temporal modulation cues conveying F0 information is enhanced  
10 for adults speaking a tonal language. PACS numbers: 43.71 Rt, 43.71 Hw, 43.66 Mk

11

## 12 **I. INTRODUCTION**

13 Tonal variations at the syllable level distinguish word meaning in tonal languages  
14 (*e.g.*, Liang, 1963). Native listeners rely mainly on fundamental-frequency (F0)—and thus,  
15 voice-pitch cues—to discriminate lexical tones. However, other acoustic cues such as duration,  
16 amplitude or voice quality may also play a secondary role (*e.g.*, Kuo *et al.*, 2008; Whalen and  
17 Xu, 1992).

18 Over the last decades, psycholinguistic studies have investigated whether being native  
19 (*i.e.*, expertise) in tonal language influences the relative weight of these acoustic cues in  
20 lexical-tone perception (Gandour and Harshman, 1978). Burnham and Francis (1997) showed  
21 that non-native (English-speaking) listeners are less accurate in discriminating lexical tones  
22 than native (Thai-speaking) listeners (see also Burnham and Mattock, 2007). Their results  
23 also suggested that non-native listeners rely more on mean F0 to perceive tones compared to  
24 native listeners who are able to categorize F0 patterns in spite of phonetic and tonal variability  
25 (*i.e.*, small variations in pitch within the same category). Lee *et al.* (2008) explored further the

1 influence of the native language on the identification of lexical tones by using degraded  
2 speech sounds (*i.e.*, “fragmented” tones obtained by removing a variable number of F0  
3 periods at the onset, center or final part of the syllables). Lexical tone identification  
4 performance was affected by these degradations of F0 information for the non-native listeners  
5 (English speakers learning Mandarin) only. These results confirm that non-native listeners  
6 rely heavily on mean F0 whereas native listeners (Mandarin speakers) rely more on F0  
7 direction (see also Huang and Johnson, 2010). Altogether, these studies are compatible with  
8 the notion that expertise in tonal language influences the relative importance of the acoustic  
9 cues involved in lexical-tone perception. From a wider perspective, they are consistent with  
10 the idea that linguistic experience shapes the weight of acoustic cues in speech perception  
11 (*e.g.*, Burnham and Mattock, 2007).

12         The search for the acoustic cues used in discriminating or identifying lexical tones has  
13 been recently renewed by the use of “vocoders” that manipulate the spectral and temporal  
14 modulation components of speech signals (see Shamma and Lorenzi, 2013 for a review). The  
15 slowest amplitude-modulation cues (AM, corresponding to the relatively slow variations in  
16 amplitude over time) play a major role in consonant recognition, whereas the fast AM cues,  
17 frequency-modulation cues (FM, corresponding to the oscillations in instantaneous frequency  
18 close to the center frequency of the frequency band), and fine spectral details are more  
19 important in lexical-tone recognition. Chinese-speaking listeners have been shown to rely  
20 more on the FM cues (*e.g.*, Wang *et al.*, 2011; Xu and Pfingst, 2003) cues compared to  
21 English- or French-speaking listeners who hinge on AM cues to identify native speech sounds  
22 (*e.g.*, Shannon *et al.*, 1995; Smith *et al.*, 2002). Fu *et al.* (1998) showed that for native  
23 Mandarin speakers, lexical-tone recognition was more affected by a reduction of temporal  
24 resolution (that is by the selective attenuation of the fast [F0-related] AM cues above 50 Hz)  
25 than by a reduction of spectral resolution (tones were vocoded using a decreasing number [4,

1 3, 2, and 1] of broad frequency bands). In contrast, consonant and vowel recognition was  
2 found to be mostly affected by a reduction of spectral resolution. In addition, Xu *et al.* (2002)  
3 and Kong and Zeng (2006) showed a clear dependence of lexical tone recognition on spectral  
4 resolution when the number of frequency bands varied from 1 to 32.

5         However, the vocoder-based studies cited above did not compare *directly* lexical-tone  
6 recognition across listeners from different linguistic backgrounds using the same material and  
7 procedure. Thus, it is still unclear whether the native language of adult speakers influences the  
8 weight of the spectro-temporal modulation cues conveying F0 information in speech  
9 perception. The goal of the present pilot study was to assess the effect of two different native  
10 languages on the ability to use fine spectral details and FM cues in lexical-tone  
11 discrimination. This comparison should reveal to what extent native language shapes the  
12 perception of speech modulation cues. Three conditions were designed to: 1) preserve the  
13 original speech modulation cues of lexical tones, 2) degrade the fine spectral details and FM  
14 speech cues of lexical tones and thus the F0-related information and 3) generate sounds (click  
15 trains) preserving only the F0-related FM cues of the original lexical tones. First, it was  
16 hypothesized that native French-speaking listeners should be less accurate in lexical-tone  
17 discrimination than native Mandarin-speaking listeners. Second, if Mandarin listeners rely  
18 more on F0 direction than French listeners, they should be more affected by the degradation  
19 of fine spectral and FM cues than the French ones. Third, if exposure to a tonal language  
20 results in a higher perceptual weight of the fine spectral than temporal cues in perceiving F0  
21 information for both speech and click-train sounds, Mandarin-speaking listeners should be  
22 more accurate in the discrimination of F0 contours in the click-train condition than French-  
23 speaking listeners (see Xu *et al.*, 2002). The present study used a same/different task to assess  
24 the discrimination of lexical tones. Three Thai lexical tones were used in order to present non-  
25 native stimuli for both French and Mandarin-speaking listeners and use similar stimuli than

1 those used in Burnham and Francis (1997): low, rising, and falling F0 patterns. We assumed  
2 that the discrimination abilities of native Mandarin-speaking listeners should be facilitated by  
3 their experience in lexical tone processing. Participants had to discriminate the following  
4 three contrasts: rising/low, rising/falling, and low/falling using a same/different task. The  
5 rising/low contrast would be the most difficult to discriminate for non-lexical users because of  
6 the highly similar F0 trajectories until the mid-point of the tone. It is not the case for the rising  
7 and falling tones that have totally different F0 trajectories and differ on other cues such as  
8 duration, making them easier to distinguish (see Abramson, 1978). In addition, two different  
9 inter-stimulus intervals (ISI) were used (500 and 1500 ms) in the present same/different task.  
10 As suggested in previous studies (see Burnham and Francis, 1997; Clément *et al.*, 1999;  
11 Werker and Tees, 1984) long ISI may affect information loss in the short-term memory  
12 representation of the cues used to discriminate two sounds. We assumed that a long ISI (1500  
13 ms) may affect the rate of information loss in the short-term memory representation of the  
14 voice-pitch cues used to discriminate lexical tones compared to a short ISI (500 ms). This  
15 effect may be greater for the French-speaking listeners than Mandarin-speaking listeners.

## 16 **II. METHOD**

### 17 **A. Participants**

18 One hundred and twenty young adult subjects, were split into 12 groups of 10 subjects.  
19 No participant reported any history of speaking or hearing disorders. Sixty native French  
20 speakers, born and raised in France, were tested in Paris, France (age range = [21-34 years];  
21 mean = 24; standard deviation (SD) = 2.5 years; 24 females). They did not learn any tonal  
22 language. The other 60 participants were native Mandarin speakers, born and raised in  
23 Taiwan, and tested in Taipei, Taiwan (age range = [19-29]; mean = 23 years; SD = 2.5 years;  
24 33 females). For each participant the musical experience was assessed and 52 native French-

1 speaking and 44 native Mandarin-speaking listeners reported to practice music. Table 1  
2 summarizes the participants' characteristics.

3 -Table 1 about here-

#### 4 **B. Stimuli**

5 Three Thai tones (rising, falling and low) were pronounced by a native female speaker  
6 asked to speak clearly (F0 range=100-350 Hz, as estimated by YIN algorithm; de Cheveigné  
7 and Kawahara, 2002) with the syllable /ba/ (see the Figure 1 for a representation of the F0  
8 trajectories, the sound files also available online). All stimuli were recorded digitally via a 16-  
9 bit A/D converter at a 44.1-kHz sampling frequency. In each lexical tone, eight different  
10 tokens were chosen because of their higher clarity. The mean duration of the stimuli was  
11 661.6 ms (SD=32.3 ms) for the rising tones, 509.9 ms (SD=36.8) for the falling tones, and  
12 636 ms (SD=31.2) for the low tones.

13 -Figure 1 about here-

14 In the first condition ("Intact"), each digitized signal was passed through a bank of 32,  
15 fourth-order gammatone filters (Gnansia *et al.*, 2009; Patterson, 1987) -also called "analysis  
16 filters" hereafter, each 1- $ERB_N$ -wide (average equivalent-rectangular-bandwidth of the  
17 auditory filter as determined using young normally hearing listeners tested at moderate sound  
18 levels; Moore, 2007) with CFs uniformly spaced along an  $ERB_N$ -number scale (one filter per  
19  $ERB_N$ ) ranging from 80 to 8020 Hz. The Hilbert transform was then applied to each bandpass  
20 filtered speech signal to extract the AM and FM components. The temporal envelope (AM  
21 component) was lowpass filtered using a zero-phase Butterworth filter (36 dB/octave rolloff).  
22 Cochlear filtering (modelled here by gammatone filtering) imposes limitations on the  
23 maximum AM rate. As in Gnansia *et al.* (2009), we adjusted the cutoff frequency of the  
24 lowpass filter (following gammatone filtering) to  $ERB_N/2$ ; the  $ERB_N$  corresponded to that of  
25 the (normal) cochlear filter tuned to the geometric center of the 1- $ERB_N$  wide gammatone

1 filter. In each band, the FM carrier was then multiplied by the filtered AM function. Finally,  
2 the narrowband speech signals were added up and the level of the resulting speech signal was  
3 adjusted to have the same root-mean square (RMS) value as the input signal. In this condition,  
4 speech processing resulted in near-perfect stimulus reconstruction.

5 In the second condition (“Vocoded”), the same signal processing scheme was used,  
6 except that each digitized signal was passed through a bank of 8, fourth-order gammatone  
7 filters, each 4- $ERB_N$ -wide with CFs uniformly spaced along an  $ERB_N$ -number scale (one filter  
8 per  $ERB_N$ ) ranging from 80 to 8020 Hz. In this condition, the cut-off frequency of the low-  
9 pass filter used to extract temporal envelopes was set to  $ERB_N/2$ ; the  $ERB_N$  corresponded to  
10 that of the (normal) cochlear filter tuned to the geometric center of the 4- $ERB_N$  wide  
11 gammatone filter. The original FM carriers were replaced by sine wave carriers with  
12 frequencies at the center frequency of the gammatone filters, and with random starting phase  
13 in each analysis band.

14 In a third condition (“F0-modulation”), the stimuli were generated by first extracting  
15 the F0 trajectory of each original lexical tone using the YIN algorithm (de Cheveigné and  
16 Kawahara, 2002; implemented in MATLAB, MathWorks, Natick, MA). Then, this F0  
17 trajectory was used to modulate the F0 of a periodic click train (more precisely, the signal was  
18 a periodic click train of 88-  $\mu$ s square (*i.e.*, monophasic) pulses, which were repeated at a rate  
19 equal to  $1/F0$ ). A first order (butterworth) lowpass filter was used to limit the frequency range  
20 below 22050 Hz. The “F0-modulation” signals have the same duration as the original lexical  
21 tones (sound samples are provided on-line in the JASA supplementary material).

22 This study intended to measure lexical-tone discrimination on the sole basis on  
23 temporal-envelope (AM) cues for lexical-tone users and non-users. Note that the stimuli were  
24 not normalized in duration, because duration cues are considered to be an element of



1 temporal-envelope cues (Rosen, 1992). Thus, normalization in duration would degrade  
2 envelope cues.

### 3 **C. Procedure**

4 A same/different task like Burnham and Francis (1997) was used to assess  
5 discrimination using E-Prime 2.0 software (Psychology Software Tools). Two different ISIs  
6 (500 and 1500 ms) were used. In each vocoder condition (Intact, Vocoded or F0-  
7 modulations), eight practice trials, with feedback, were first presented with unrelated sounds  
8 (unprocessed syllables /ko/ and /mi/) to train subjects with the task. This was followed by a  
9 test phase composed of 48 test trials, without feedback. Half of the trials consisted of the  
10 presentation of two stimuli of the same category, and the other half in the presentation of two  
11 stimuli belonging to two different categories (8 trials per contrast: rising/low, rising/falling,  
12 and low/falling). “Same” and “different” trials were presented in random order within two  
13 blocks (of 24 trials). Each subject was randomly assigned to a given experimental condition  
14 (Intact, Vocoded or F0-modulations) and a given ISI duration (500 or 1500 ms) in order to  
15 reduce training effect between conditions and prevent recognition of the sounds in the  
16 degraded conditions. Thus, six independent groups of ten adults from each language  
17 background were tested in a soundproof booth in Paris or in Taipei using the same material  
18 and by the same experimenter. All stimuli were presented in free field using a Fostex (model  
19 PM0.5) speaker at a 70 dB SPL. Subjects sat in front of a computer controlling the experiment  
20 and 50 cm from the speaker located on their right side (*i.e.*, at 40 deg azimuth and 0 deg  
21 elevation). Subjects were instructed to listen carefully to the pairs of sounds and to respond as  
22 fast and as accurately as possible by pressing two different keys (indicating same or different).  
23 The subject’s accuracy was estimated by a  $d'$  score where  $d' = Z[p(\text{hit}) - Z[p(\text{false alarms})]]$   
24 (see Macmillan and Creelman, 1991). If the hit rate was 1.0 or the false alarm rate was 0,  $d'$

1 was calculated after adjusting the hit rate or false alarm rate by the reciprocal of the number of  
2 trials.

### 3 **III. RESULTS**

4 The  $d'$  scores of the native-Mandarin and native-French participants for each tone  
5 contrast are represented in Figure 2 for the “Intact”, “Vocoded” and “F0-modulations”  
6 conditions. A  $d'$  of 0 corresponds to chance, and a  $d'$  of 2.68 corresponds to perfect  
7 discrimination. French and Mandarin speakers showed similar discrimination performance in  
8 the “Intact” speech condition. In the “Vocoded” speech condition, the performance of both  
9 groups decreased significantly but remained above chance level. Moreover, Mandarin  
10 speakers scored lower than French speakers in this condition (when the fine spectro-temporal  
11 modulation cues conveying voice-pitch information were severely degraded). In the “F0-  
12 modulations” condition, Mandarin speakers showed slightly better discrimination of (F0)  
13 pitch contours compared to French speakers.

14 -Figure 2 about here-

15 Even if native French-speaking listeners had more practice in music than native  
16 Mandarin-speaking listeners [mean=6.30, sd=6.14, vs. mean=3.61, sd=3.8 for years of  
17 musical practice], a preliminary analysis of variance (ANOVA) on the total  $d'$  score showed  
18 no main effect of the factor Musician or interaction with Language. Thus, data were collapsed  
19 across this variable in the main analyses. A repeated-measures ANOVA was performed with  
20 Condition (Intact vs. Vocoded vs. F0-modulations), ISI (500 ms vs. 1500 ms) and Language  
21 (French vs. Mandarin) as between-subject factors and Contrast (rising/low vs. rising/falling  
22 vs. low/falling) as within-subject factor, to assess the role of Language and ISI in the three  
23 experimental conditions on the  $d'$  scores. This analysis revealed a main effect of Condition  
24 [ $F(2,108)=125.54, p < .001$ ] and a *post-hoc* Tukey’s HSD test showed that the “Vocoded”  
25 speech condition led to lower discrimination scores compared to “Intact” and “F0-

1 modulations” conditions (see Figure 2). No main effect of ISI or Language was found.  
2 However, a main effect of Contrast was found [ $F(2,216)=5.4, p=.005$ ]. *Post-hoc* comparisons  
3 (Tukey’ HSD test) showed that as expected, the “rising-falling” contrast was easier to  
4 discriminate than “rising-low”; no difference was observed between the other two contrasts.  
5 Moreover, a significant Condition x Contrast interaction was observed [ $F(4,216)=4.1, p=.003$ ]  
6 indicating that the “rising-falling” contrast was easier to discriminate than the “rising-low”  
7 contrast in the “Vocoded” speech condition. Furthermore, the significant interaction of  
8 Condition x Contrast x Language [ $F(4,216)=3.51, p=.008$ ] revealed that the higher scores  
9 obtained for the “rising-falling” contrast were mainly obtained by Mandarin-speaking  
10 listeners.

11 The significant interaction Contrast x ISI x Language [ $F(2,216)=3.28, p = .04$ ]  
12 indicated that the better *d'* scores for the “rising-falling” contrast were exhibited by the  
13 French-speaking listeners with an ISI of 500 ms and by the Mandarin ones with an ISI of  
14 1500 ms. Finally, a significant interaction between Condition x ISI x Language  
15 [ $F(2,108)=4.12, p = .02$ ] showed that French-speaking participants were better than Mandarin  
16 ones with a short ISI in the “Vocoded” condition.

17 A significant interaction Condition x Language was also found [ $F(2,108)=5.79, p$   
18  $=.004$ ]. To explore further this interaction and to compare the discrimination performance of  
19 Mandarin and French-speaking listeners in each condition, separated repeated-measures  
20 ANOVAs were run with Language (French vs. Mandarin) and ISI (500 ms vs. 1500 ms) as  
21 between-subject factors and Contrast (rising/low vs. rising/falling vs. low/falling) as within-  
22 subject. In the “Intact” condition, no main effect or interaction with Language was observed.  
23 A main effect of Contrast was observed [ $F(2;72) = 3.75, p = .03$ ] indicating that the “falling-  
24 low” contrast was more difficult to discriminate than the two other contrasts. In the  
25 “Vocoded” speech condition, a main effect of Contrast was observed [ $F(2;72) = 4.69, p = .01$ ]

1 but indicated that the “rising-falling” contrast was easier to discriminate than the “rising-low”.

2 A marginal effect of Language was observed [ $F(1;36) = 3.83$ ;  $p = .058$ ], showing that French

3 participants tended to be slightly better at discriminating the vocoded lexical tones than

4 Mandarin participants. Although the  $d'$  scores of both groups remained above chance level

5 (Student  $t$  test; all  $p < .001$ ), a significant interaction between Contrast and Language

6 [ $F(2,72)=3.4$ ,  $p = .04$ ] was observed. *Post-hoc* comparisons (Tukey’s HSD test) indicated that

7 the  $d'$  scores varied between contrasts only for Mandarin-speaking listeners and that they

8 better discriminated the “rising-falling” than the “falling-low” contrast. A significant

9 interaction between ISI and Language was also found [ $F(2,72)=4.39$ ,  $p = .04$ ] indicating that

10 French speaking-listeners were better than the Mandarin ones with a ISI of 500 ms. In the

11 “F0-modulations” condition, a main effect of Language was observed [ $F(1,36)=7.31$ ,  $p = .01$ ]

12 and *post-hoc* comparisons revealed that Mandarin-speaking listeners obtained (slightly)

13 higher  $d'$  scores compared to French-speaking listeners.

#### 14 **IV. DISCUSSION**

15 The present study aimed to investigate the role of native language on the processing of

16 spectro-temporal cues in lexical-tone discrimination. In apparent contrast with previously

17 published investigations on lexical-tone discrimination (*e.g.*, Burnham and Francis, 1997;

18 Hallé *et al.*, 2004; Sun and Huang, 2012), both French- and Mandarin-speaking listeners were

19 able to correctly perceive differences in pitch contours with the present lexical tones. The

20 absence of difference between language groups results from a ceiling effect (that is from the

21 high performance of both groups for the current discrimination task and for the present speech

22 stimuli that were carefully selected from a large set of clearly articulated utterances). As

23 expected in the “Vocoded” speech condition, results indicate an effect of native language on

24 the perception of F0 variations and suggest that lexical-tone users are more dependent on fine

25 spectral and FM cues than non-users when perceiving lexical tones. Moreover, French-

1 speaking listeners are better able to make use of the remaining (AM) information (conveying  
2 duration and loudness information; *cf.* Rosen, 1992 (p. 74, lines 13-14)) than Mandarin-  
3 speaking listeners in this condition. One possibility is that the experience with French prosody  
4 and phonological categories makes French-speaking listeners more likely to focus on the AM  
5 cues available (related to rhythm information) in the Vcoded stimuli and potentially relevant  
6 for French language. Moreover, these results are consistent with previous studies showing that  
7 native lexical-tone users rely more on the F0 direction than non-users (*e.g.*, Lee *et al.*, 2008,  
8 2010). Furthermore, the duration of ISI influenced French and Mandarin participants’  
9 performance differently in that Vcoded condition. As expected, better performance for the  
10 “rising-falling” contrast was observed with a short ISI for French speakers and with a long ISI  
11 for Mandarin speakers. This may reveal that native language affects the rate of information  
12 decay in the short-term memory representation (and/or its use for further perceptual  
13 processes) of the voice-pitch cues used to discriminate lexical tones (Mandarin speakers  
14 showing less information decay than French speakers).

15 Finally, when the fine spectro-temporal modulations conveying the voice-pitch  
16 information were presented for discrimination using “F0-modulations” sounds, Mandarin-  
17 speaking listeners showed better discrimination of (F0) pitch contours compared to French-  
18 speaking listeners. These results are in line with several studies showing an effect of native  
19 language on the identification of pitch contours in non-linguistic signals such as sine waves,  
20 harmonic complex tones, or iterated rippled noises (*e.g.*, Bent *et al.*, 2006; Swaminathan *et*  
21 *al.*, 2008; Xu *et al.*, 2006).

22 Overall, the present results suggest that Mandarin-speaking listeners are more  
23 dependent on F0 variations—and thus on FM and fine spectral cues—than French-speaking  
24 listeners when discriminating lexical tones. The results of this pilot study are consistent with  
25 the notion that native language shapes the weight of spectro-temporal fine structure cues in

1 processing speech sounds. Results obtained with click trains suggest that this influence of  
2 native language could extend to non-linguistic sounds. Thus, temporal modulation processing  
3 in the auditory system may be influenced by higher-level mechanisms fine-tuned by language  
4 expertise. This influence is not incorporated in current models of modulation processing  
5 (Jørgensen and Dau, 2013). However, our conclusions should be taken with caution because  
6 several factors such as genetic and socio-cultural backgrounds and environmental factors were  
7 not controlled in the present study. Further work investigating the development of lexical-tone  
8 processing for infants learning tonal and non-tonal languages is required to address these  
9 issues. Moreover, the perceptual strategies (*i.e.*, Bent *et al.*, 2006) used by native and non-  
10 native lexical-tone listeners when listening to degraded lexical tones may be further explored  
11 using a more cognitively demanding task such as an identification task.

12

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19

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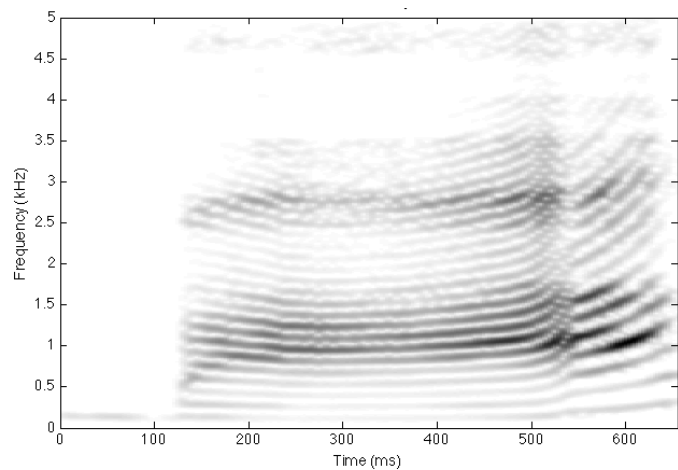
## 16 **Figure captions**

17 **Table 1.** Participants’ information

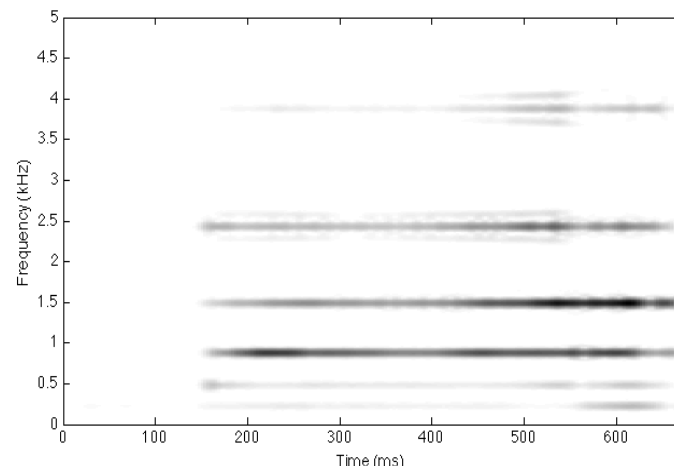
18 **Figure 1.** Spectrograms of the Intact (left panels), Vocoded (middle panels) and F0-  
19 modulation (right panels) versions of a /ba/ rising (first row), /ba/ falling (second row) and  
20 /ba/ low (third row) stimulus.

21 **Figure 2.**  $d'$  scores of the Mandarin-speaking and French-speaking listeners in the three  
22 experimental conditions (Intact, Vocoded and F0-modulations) for each lexical-tone pair (RL:  
23 Rising-Low; RF: Rising-Falling; FL: Falling- Low) presented in the two ISI (500 ms; 1500  
24 ms). The bars represent the standard errors.

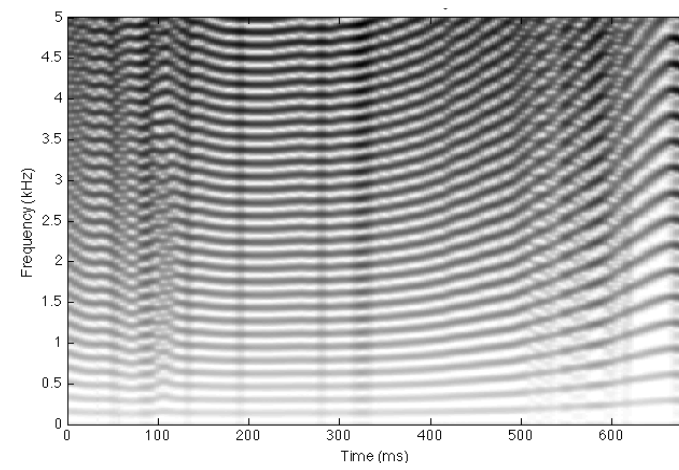
| Condition      | Isi  | Language | mean age (years) | sd age (years) | age range (years) | number of females | number of musicians | mean musical practice (years) | sd of musical practice | range of musical practice (years) |
|----------------|------|----------|------------------|----------------|-------------------|-------------------|---------------------|-------------------------------|------------------------|-----------------------------------|
| Intact         | 1500 | French   | 25               | 3.4            | 22-31             | 7                 | 6                   | 6.9                           | 7.7                    | 0-23                              |
| Intact         | 500  | French   | 24               | 1.9            | 21-27             | 6                 | 6                   | 5.9                           | 6                      | 0-15                              |
| Intact         | 1500 | Mandarin | 24               | 2.4            | 22-29             | 7                 | 5                   | 3.4                           | 4.1                    | 0-14                              |
| Intact         | 500  | Mandarin | 23.6             | 2.5            | 20-27             | 6                 | 6                   | 4.9                           | 2.9                    | 0-10                              |
| Vocoded        | 1500 | French   | 23.8             | 1.4            | 22-26             | 1                 | 6                   | 5                             | 5.3                    | 0-15                              |
| Vocoded        | 500  | French   | 25.3             | 3.7            | 22-34             | 0                 | 7                   | 7.3                           | 6.3                    | 0-20                              |
| Vocoded        | 1500 | Mandarin | 22.1             | 1.7            | 19-24             | 4                 | 4                   | 4.5                           | 4                      | 0-12                              |
| Vocoded        | 500  | Mandarin | 23.2             | 2.9            | 20-29             | 6                 | 6                   | 3.8                           | 4.1                    | 0-13                              |
| F0-modulations | 1500 | French   | 24.9             | 1.97           | 22-29             | 7                 | 6                   | 5.4                           | 6                      | 0-16                              |
| F0-modulations | 500  | French   | 24.6             | 1.9            | 22-28             | 3                 | 7                   | 7.3                           | 6.5                    | 0-18                              |
| F0-modulations | 1500 | Mandarin | 23.9             | 3.1            | 20-28             | 5                 | 4                   | 2                             | 2.2                    | 0-7                               |
| F0-modulations | 500  | Mandarin | 21.7             | 1.9            | 20-26             | 6                 | 5                   | 3.4                           | 4.7                    | 0-15                              |



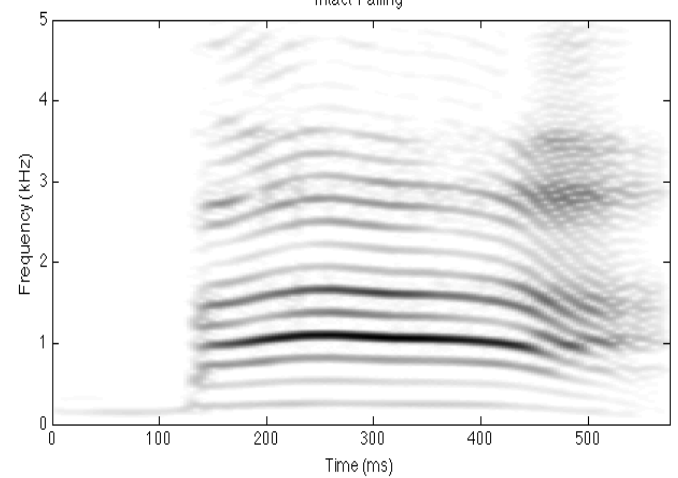
Intact-Falling



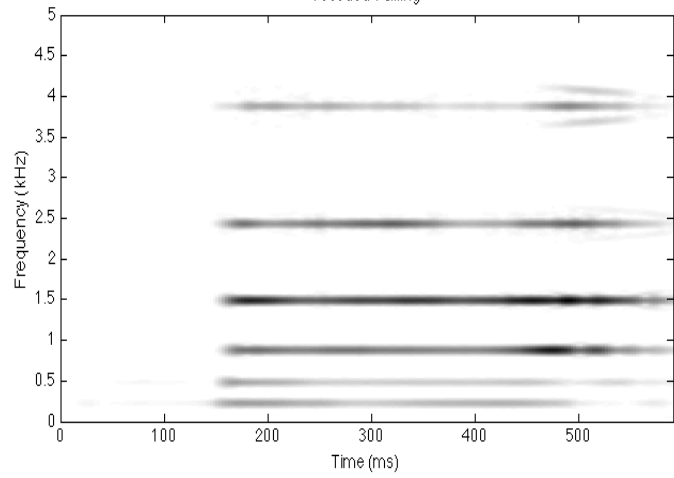
Vocoded-Falling



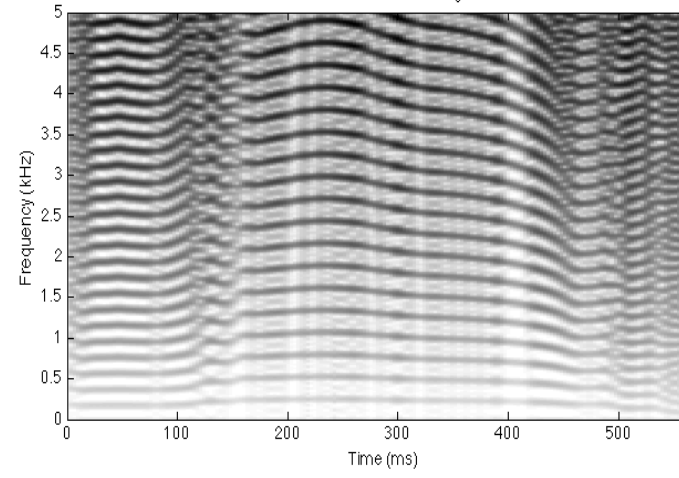
F0 modulations-Falling



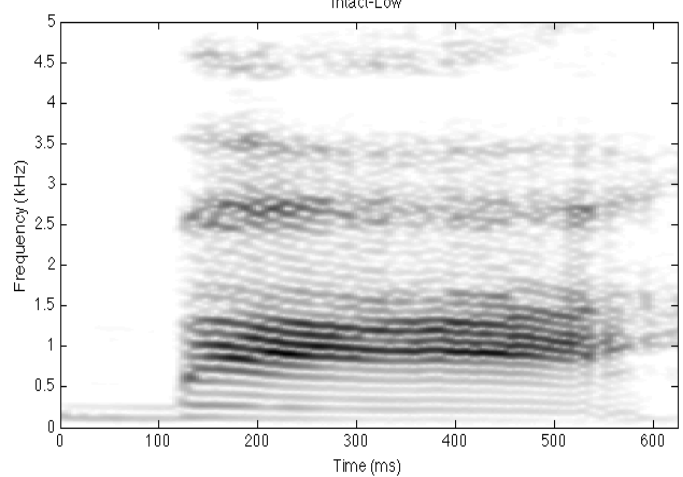
Intact-Low



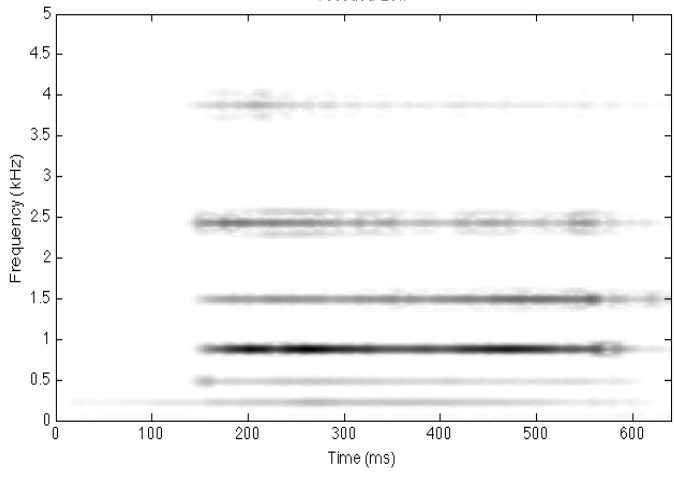
Vocoded-Low



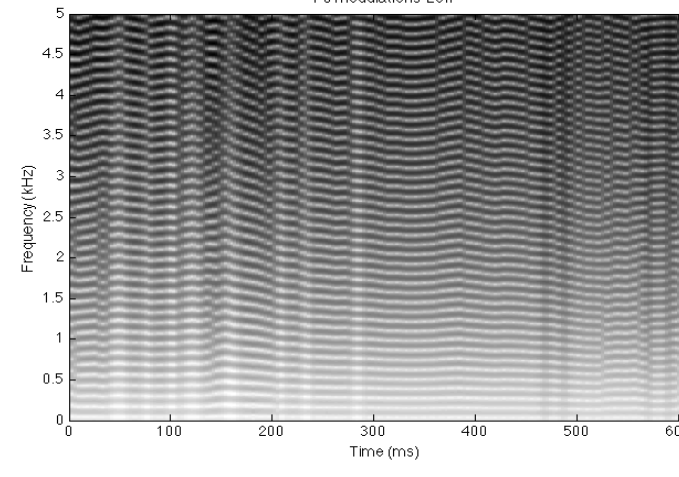
F0 modulations-Low



Intact-Falling



Vocoded-Falling



F0 modulations-Falling

