frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 04 July 2011
doi: 10.3389/fpsyg.2011.00145

# Tone language fluency impairs pitch discrimination

**Isabelle Peretz*, Sébastien Nguyen and Stéphanie Cummings**

*International Laboratory for Brain, Music and Sound Research (BRAMS), Department of Psychology, University of Montreal, Montreal, QC, Canada*

**Edited by:**
*Lutz Jäncke, University of Zurich, Switzerland*

**Reviewed by:**
*Gottfried Schlaug, Beth Israel Deaconess Medical Center and Harvard Medical School, USA*
*Steven Brown, McMaster University, Canada*

***Correspondence:**
*Isabelle Peretz, International Laboratory for Brain, Music and Sound Research (BRAMS), Université de Montréal, Pavillon 1420 Mont-Royal, Montreal, QC, Canada H2V 4P3.*
*e-mail: isabelle.peretz@umontreal.ca*

Here we present evidence that native speakers of a tone language, in which pitch contributes to word meaning, are impaired in the discrimination of falling pitches in tone sequences, as compared to speakers of a non-tone language. Both groups were presented with monotonic and isochronous sequences of five tones (i.e., constant pitch and intertone interval). They were required to detect when the fourth tone was displaced in pitch or time. While speakers of a tone language performed more poorly in the detection of downward pitch changes, they did not differ from non-tone language speakers in their perception of upward pitch changes or in their perception of subtle time changes. Moreover, this impairment cannot be attributed to poor musical abilities since the impairment remains unchanged when individual differences in musical pitch-based processing is taken into account. Thus, the impairment appears highly specific and may reflect the influence of statistical regularities of tone languages.

**Keywords: tone language, pitch perception, individual differences in musical abilities**

## INTRODUCTION

A fundamental question that is currently hotly debated is to what extent music processing shares perceptual mechanisms with language. One way to examine this question is to study transfer effects between musical and language abilities, as such a transfer may be mediated by shared mechanisms. For example, Slevc and Miyake (2006) showed that native Japanese speakers with high musical aptitude spoke English with better pronunciation than did their peers with less musical aptitude. Similarly, speakers of tone languages are better able to reproduce musical pitch patterns in singing than English speakers (Pfordresher and Brown, 2009). The latter domain-transfer effect from language to music suggests that tone language acquisition, that makes use of small pitch contrasts to convey meaning, fine-tunes pitch perception which in turn can be carried over to musical tasks. The objective of the present study was to re-examine this issue.

In the present study, we tested whether early exposure to a tone language may confer a sensory advantage in discriminating subtle pitch deviations in non-speech tone sequences. To this aim, we asked both speakers of a tone language, mostly Mandarin, and speakers of non-tone languages (mostly French), to detect pitch changes that were at or just above threshold. To assess the specificity of the transfer, we used a control condition in which the task was to detect equally subtle time changes. In both conditions, participants heard standard sequences of five piano tones presented monotonically (constant pitch) and isochronously [constant intertone interval (ITI)], as well as comparison sequences in which the fourth tone was displaced in pitch or time. Their task was to detect a change in the fourth tone of a sequence.

Musicians were excluded so as to control for possible transfer effects due to musical training rather than language experience. Indeed, it has been shown that musicians outperformed non-musicians in the processing of lexical tones (Wong et al., 2007; Lee and Hung, 2008). In such cases, the positive transfer effects observed between music and language abilities could be the consequence of other factors than shared sensory processing. One likely mediating factor is that musicians have enhanced attentional or executive control capacities as compared to non-musicians (Bialystok and DePape, 2009). Yet, non-musicians might differ in musical capacity. In order to measure individual differences in musical abilities, all participants were tested with a standardized battery – the Montreal Battery of Evaluation of Amusia (MBEA; Peretz et al., 2003) – that was developed for Westerners but that showed similar sensitivity in speakers of a tone language (Nan et al., 2010).

## MATERIALS AND METHODS

### PARTICIPANTS

Twenty-four speakers of a tone language (referred to as tone speakers) and 25 speakers of a non-tone language (referred to as non-tone speakers) were tested in Montreal (see **Table 1**). The native language of tone speakers was Mandarin ($n = 18$), Vietnamese ($n = 4$), or Cantonese ($n = 2$); all had immigrated to Canada in adulthood and had spoken French and/or English as a second language for 6 years on average (SD = 5). Otherwise, tone and non-tone speakers were matched for age, education, duration of musical lessons, and handedness. None of the participants reported any hearing disorder and all were paid for their participation.

To screen for any musical deficit and to assess individual differences in musical abilities, all participants were tested on the MBEA, a validated and standardized collection of six tests developed to assess normal music perception and memory (Peretz et al., 2003). Each test contained 30 same – different classification trials in which a standard melody was followed by a comparison melody. For trials where the comparison melody differed from the standard, one note was altered in one of the following ways: it was out of the scale of the melody while preserving the contour (scale test), it changed the contour of the melody while preserving the scale (contour test), or it changed the intervallic distance between two successive notes while maintaining the contour and the scale (interval test). The rhythm test also used a same–different classification task with 30 trials. In half the trials, the duration of two adjacent notes was changed so that the rhythmic grouping of the melody was altered. For the metric test, half the 30 trials were written in duple meter and half in triple meter and the participant was asked to classify each trial as either a march or a waltz. Finally, recognition of melodies (memory test) was evaluated. In this last test, participants had to discriminate "old" melodies that they heard in the previous five tests from "new" melodies similar in structure to the old melodies but never heard before. The melodies were novel, written in the Western tonal musical system and presented on a piano timbre; they contained 10 notes on average.

The scores obtained on the MBEA revealed that one tone speaker performed 2 SD below the tone speakers' average performance ($M = 84\%$; SD = 7). The data of this amusic participant were excluded. As can be seen in **Table 2**, the two groups obtained similar scores on the MBEA tests, except for the scale test on which tone speakers obtained lower scores than non-tone speakers. Nevertheless, there was no significant Group effect [$F(1, 47) = 1.66$, $p = 0.20$] nor interaction between Group and the MBEA tests [$F(4, 184) = 1.38$, $p = 0.23$].

### MATERIAL AND PROCEDURE

The material and procedure were adapted from Hyde and Peretz (2004). Stimuli consisted of 21 different sequences, each containing five successive tones. In the standard sequence, all tones were 120 ms long, played at the pitch level of C6 (1047 Hz), and synthesized with a piano timbre; the ITI (onset to onset) was 350 ms. In the comparison sequences, the fourth tone was altered. In the 10 pitch-altered sequences, the fourth tone was displaced by one of five pitch distances upward or downward from C6; the five pitch distances used ranged from 1 Hz (1.56 cents) to 15 Hz (25 cents; 100 cents corresponds to 1 semitone; **Figure 1**). The 1 Hz distance was chosen so as to be at threshold at a reference frequency above 1000 Hz (e.g., Moore, 1973). In the 10 time-altered sequences, the fourth tone was displaced by one of five temporal increments earlier or later than its isochronous position; the five temporal increments ranged from 6 to 14% of the ITI.

Participants were tested individually, with separate sessions for the pitch and time tasks, presented in a counterbalanced order across subjects. In both tasks, they were asked to press a "yes" button when they detected a change and a "no" button when they were unable to detect a change. Trials were randomized, and half contained no change (i.e., the standard monotonic, isochronous sequence). Participants did not receive feedback but were informed about the nature of the possible change and the location where it could occur. They also received 20 practice trials with feedback after each trial. Each test session comprised 360 sequences (180 standard sequences, 18 of each of 10 altered sequences). The stimuli were presented bilaterally through Sennheiser HD450 headphones in a quiet room, at an intensity level of 70 dB SPL(A).

**Table 1 | Participants' characteristics.**

| | Tone speakers ($n = 24$) | Non-tone speakers ($n = 25$) | *t*-test[a] |
|---|---|---|---|
| Age (SD) | 34 (7) | 31 (11) | n.s. |
| Gender | 13 F | 15 F | – |
| Handedness | 22 R | 22 R | – |
| Education duration in years (SD) | 16 (1) | 17 (3) | n.s. |
| Musical training[b] (SD) | 2.36 (1.26) | 2.22 (1.45) | n.s. |

*F, female; R, right-handed.*
[a]*Two-tailed.*
[b]*Based on a scale of musical training with 1 = less than a year; 2 = 1–3 years; 3 = 4–6 years; 4 = 7–10 years; 5 = more than 10 years.*

**Table 2 | Percentage of correct responses (SD) obtained on the Montreal Battery of Evaluation of Amusia (MBEA) by speakers of a tone and non-tone language.**

| | Tone speakers ($n = 24$) | Non-tone speakers ($n = 25$) | *t*-test[a] |
|---|---|---|---|
| Scale | 82 (8) | 87 (10) | $p = 0.04$ |
| Contour | 82 (10) | 87 (8) | n.s. |
| Interval | 84 (8) | 87 (9) | n.s. |
| Rhythm | 90 (7) | 88 (9) | n.s. |
| Meter | 84 (17) | 87 (11) | n.s. |
| Memory | 89 (9) | 89 (9) | n.s. |
| Global | 85 (6) | 87 (6) | n.s. |

[a]*Two-tailed.*

## RESULTS

The percentage of hits (corresponding to a "yes" response when there was a change) minus false alarms (F.A., corresponding to a "yes" response when there was no change) was computed for each participant as a function of the type, direction, and size of change. It is worth noting that the groups did not differ in correct rejections (a "no" response to a trial containing no pitch change) with 68 and 73% for the tone and non-tone speakers, respectively, $t(47) = 1.28$, $p = 0.21$.

A 2 (group) × 2 (direction) × 5 (distance) mixed-design analysis of variance (ANOVA) was computed on the percentage of hits-F.A. obtained in the pitch task. As a three-way interaction

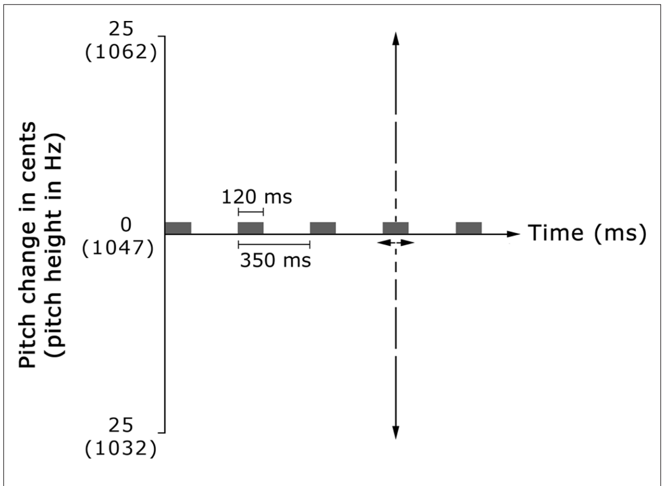


**FIGURE 1 | Schematic representation of the tone sequences that served as stimuli.**

between these factors was obtained, $F(4,188) = 4.65$, $p < 0.01$, separate ANOVAs for each direction were conducted, with Group as the between-subjects factor and Distance as the within-subjects factor. A significant two-way interaction emerged for downward pitch changes, $F(4,188) = 5.09$, $p < 0.01$. As can be seen in **Figure 2A**, tone speakers consistently performed below non-tone speakers in the detection of downward pitches, except at 1 Hz where groups did not differ, $t(47) = 1.32$, $p = 0.19$. At this smallest interval change distance, 17 tone speakers and 19 non-tone speakers performed at chance level. Statistically significant group differences emerged at 2 Hz, $t(47) = 2.05$, $p < 0.05$, and remained present at the largest pitch falls of 25 cents. In contrast, no interaction [$F(4,188) = 1.06$, $p = 0.38$] or main effect involving Group appeared for upward pitch changes [$F(1,48) = 1.67$, $p = 0.20$; **Figure 2B**].

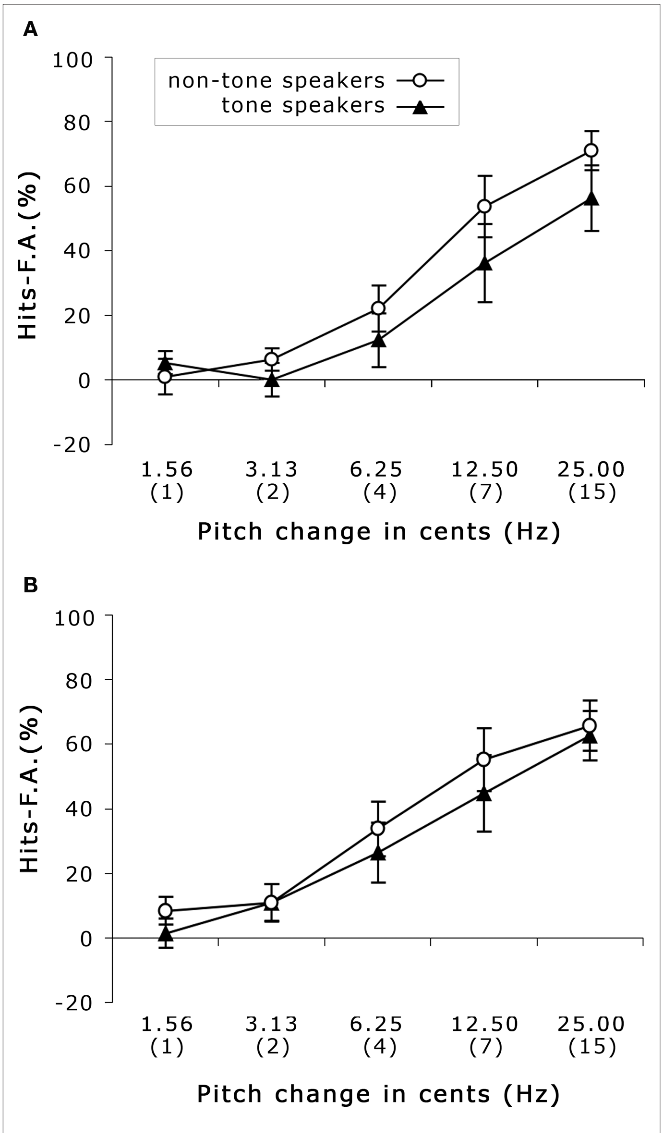


**FIGURE 2 | Performance of the tone and non-tone language speakers in the pitch change detection task: (A) downward changes; (B) upward changes.** Bars represent 2 SE.

In the time task, the ANOVA revealed no main effect or interaction involving Group ($F < 1.15$; $p$'s $> 0.10$), but a main effect of time distance, with $F(4,188) = 213.29$, $p < 0.001$ (**Figure 3**).

In order to assess whether the observed difference between the groups could be attributed to different experience of a tone language rather than to differences in musical aptitude, we assessed whether performance on each MBEA test could predict performance in the pitch change detection task (all conditions pooled together). As can be seen in **Table 3**, we found significant correlations between all pitch-related musical (Scale, Contour, and Interval) tests and performance in the pitch change detection task. It is worth pointing out that this correlation between fine-grained pitch perception and musical pitch discrimination is a general trend. It is not limited to the tone language speakers (**Figure 4**). Thus, group differences in musical aptitude are unlikely to account for the impairment observed for falling pitches in speakers of a tone language. To assess this statistically, the scores on the pitch-based musical tests were averaged and included as a covariate in a 2 (group) × 2 (direction) × 5 (distance) mixed-design ANCOVA. Essentially the same results as reported above were obtained, with a three-way interaction between all three

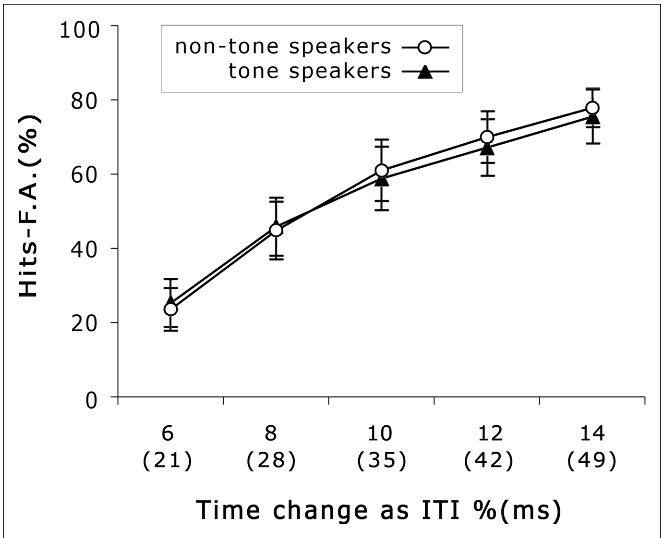


**FIGURE 3 | Performance of the tone and non-tone language speakers in the time change detection task.** Bars represent 2 SE.

**Table 3 | Bivariate correlations between performance on the pitch detection task (pooled across all conditions) and performance on each test of the MBEA.**

| MBEA | Pitch detection |
|---|---|
| Scale | 0.299* |
| Contour | 0.345* |
| Interval | 0.490** |
| Rhythm | 0.181 |
| Meter | 0.185 |
| Memory | 0.184 |

**p < 0.05; **p < 0.01 (two-tailed).*

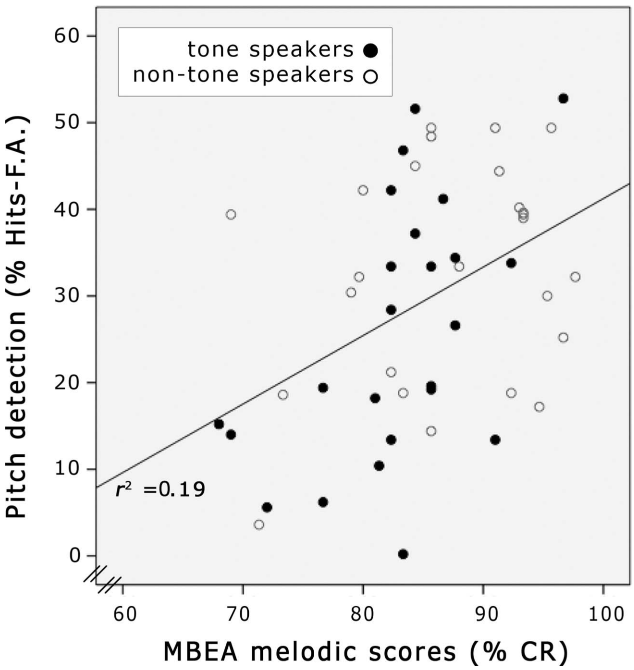


**FIGURE 4 | Individual performance pooled across conditions in the pitch detection task as a function of melodic scores averaged across scale, contour and interval tests of the MBEA, obtained by tone and non-tone language speakers.**

factors, $F(4,184) = 5.94$, $p < 0.005$, and a significant two-way interaction for the falling pitch changes only, $F(4, 184) = 4.24$, $p < 0.005$.

## DISCUSSION

Contrary to expectations, we find no evidence for enhanced perception of pitch in tone language speakers. On the contrary, we find an impairment that is limited to downward pitch changes. This impairment appears specific as tone language speakers do not differ from non-tone language speakers in their perception of upward pitch changes or in their perception of subtle time changes. Moreover, this impairment cannot be attributed to low musical aptitude since the impairment remains when individual differences in musical pitch-based processing are taken into account. Thus, fluency in a tone language interferes with the perception of falling pitches in a non-speech context.

This negative impact of tone language on pitch perception is not an isolated finding. Bent et al. (2006) found a similar pattern in the identification of pitch contours as rising, falling or flat. For the rising pitch contours, the Mandarin and English speakers performed similarly. In contrast, the tone language speakers misidentified the falling pitch contours more often than did the non-tone language speakers, which is consistent with the direction-specific impairment reported here. This response pattern can be attributed to long-term exposure to Mandarin tones in which larger pitch ranges are typically used for falling tones than for rising tones (e.g., Xu, 1994). Although the pitch rises and falls are larger in naturally produced tones than the rises and falls of the stimuli used here and in Bent et al. s' (2006) study, the differences between rising and falling that characterizes lexical tones may have influenced the criteria used for non-speech stimuli presented at near-threshold levels. In sum, the statistical pitch regularities of tone languages may lead to the use of a language-specific perceptual strategy in a non-speech context.

Recourse to a language strategy in pitch discrimination is probably optional and promoted by the use of pitch deviations near threshold. As we have observed in two other studies (Tillmann et al., 2011; Tillmann et al., submitted), the more severe is a pitch perception deficit, the more beneficial is the speech context as compared to a non-speech context. More specifically, we found that fine-grained pitch discrimination was better in spoken syllables than in acoustically matched tones in amusic individuals while normal controls showed the reverse pattern (Tillmann et al., submitted). Similarly, in another study using lexical tones, we found that amusics with a severe pitch disorder performed better on syllables than on musical analogs (Tillmann et al., 2011). Thus, speech-specific processes can influence pitch perception when differences are difficult to hear. When pitch differences are large, there would be no need to use speech processes as a compensatory strategy. This may account for the fact we do not replicate the perception results obtained by Pfordresher and Brown's (2009). While we test pitch changes that are less than 25 cents apart, Pfordresher and Brown (2009) use distances from 25 to 800 cents and find both a tone language advantage and no pitch contour effect.

While we find no support for the notion that tone language experience fine-tunes pitch perception, we find evidence that individual differences in pitch perception carry over to music perception. In both tone and non-tone language speakers, performance in the pitch detection task predicts performance in the pitch-based melodic tests of the MBEA. Thus, individual differences in fine-grained pitch perception are linked to musical abilities independently of native language.

In sum, fine-tune pitch perception might be a prerequisite for achieving high levels of melodic abilities. In the advent of pitch discrimination difficulties, as in near-threshold discrimination or in the case of amusia, speech-specific processes may contribute to the pitch discrimination task albeit in a less effective manner than by a musical or acoustic mechanism.

## ACKNOWLEDGMENTS

This research was supported by a summer fellowship from Natural Sciences and Engineering Research Council of Canada (NSERC) to Sébastien Nguyen, and by a grant from the same agency and a Canada Research Chair to Isabelle Peretz.

## REFERENCES

Bent, T., Bradlow, A. R., and Wright, B. A. (2006). The influence of linguistic experience on the cognitive processing of pitch in speech and nonspeech sounds. *J. Exp. Psychol. Hum. Percept. Perform.* 32, 97–103.

Bialystok, E., and DePape, A. M. (2009). Musical expertise, bilingualism, and executive functioning. *J. Exp. Psychol. Hum. Percept. Perform.* 35, 565–574.

Hyde, K. L., and Peretz, I. (2004). Brains that are out of tune but in time. *Psychol. Sci.* 15, 356.

Lee, C., and Hung, T. (2008). Identification of Mandarin tones by English-speaking musicians and nonmusicians. *J. Acoust. Soc. Am.* 124, 3235–3248.

Moore, B. C. J. (1973). Frequency difference limens for short-duration tones. *J. Acoust. Soc. Am.* 54, 610–619.

Nan, Y., Sun, Y., and Peretz, I. (2010). Congenital amusia in speakers of a tone language: association with lexical tone agnosia. *Brain* 133, 2635–2642.

Peretz, I., Champod, S., and Hyde, K. (2003). Varieties of musical disorders: the Montreal Battery of Evaluation of Amusia. *Ann. N. Y. Acad. Sci.* 999, 58–75.

Pfordresher, P. Q., and Brown, S. (2009). Enhanced production and perception of musical pitch in tone language speakers. *Attent. Percept. Psychophys.* 71, 1385–1398.

Slevc, L. R., and Miyake, A. (2006). Individual differences in second-language proficiency. *Psychol. Sci.* 17, 675–681.

Tillmann, B., Burnham, D., Nguyen, S., Grimault, N., Gosselin, N., and Peretz, I. (2011). Amusia (or tone-deafness) interferes with tone language perception. *Front. Aud. Cogn. Neurosci.* (in press).

Wong, P. C., Skoe, E., Russo, N. M., Dees, T., and Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nat. Neurosci.* 10, 420–422.

Xu, Y. (1994). Production and perception of coarticulated tones. *J. Acoust. Soc. Am.* 95, 2240–2253.

**Conflict of Interest Statement:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

*Received: 13 February 2011; paper pending published: 28 April 2011; accepted: 16 June 2011; published online: 04 July 2011.*

*Citation: Peretz I, Nguyen S and Cummings S (2011) Tone language fluency impairs pitch discrimination. Front. Psychology **2**:145. doi: 10.3389/fpsyg.2011.00145*

*This article was submitted to Frontiers in Auditory Cognitive Neuroscience, a specialty of Frontiers in Psychology.*