Tartu University
Faculty of Social Sciences
The Institute of Psychology

Hanna Pria Hulkko

Perception of Chinese language by Estonian musicians and non-musicians

Research paper

Supervisor: Siqi Lyu, PhD

Running head: Perception of language by musicians and non-musicians

Tartu 2024

Perception of Chinese language by Estonian musicians and non-musicians

Abstract

Music and speech have been found to have common features that serve as cues for musical and speech perception. In tonal languages such as Chinese, the meaning of a word is conveyed mainly by a change in pitch. This study examines the differences between Estonian musicians and non-musicians in their perception of Chinese. A total of 46 musicians and non-musicians who speak Estonian as native language were recruited. Data was collected through an AX discrimination experiment. Stimuli was the Chinese word JIDI and its non-linguistic equivalents (i.e., pure tones). There were three conditions, where subjects behaviorally discriminated duration change only, pitch change only, and duration + pitch change. It was found that musicians are significantly better than non-musicians at discriminating both linguistic and non-linguistic stimuli in all three conditions. The result of this study suggests that musicality has a positive effect on language perception.

Keywords: tonal language, pitch perception, musical training, AX experiment

Hiina keele tajumine eesti muusikute ja mittemuusikute poolt

Kokkuvõte

Muusikal ja kõnel on leitud ühiseid jooni, mis toimivad vihjena muusikalise ja keelelise tajumise puhul. Hiina keel liigitatakse tonaalse keele alla, mis tähendab, et sõna tähendus antakse edasi peamiselt helikõrguse muutumisega. Käesolev töö uurib erinevusi eesti muusikute ja mittemuusikute hiina keele tajumises. Katseosalisteks olid 46 eesti keelt emakeelena kõnelevat muusikut ja mittemuusikut. Andmed koguti AX diskrimineerimisülesande abil. Stiimuliks oli hiina sõna JIDI ning selle mittekeeleline vaste (lihtheli). Katses oli kolm tingimust, kus katseisikud käitumuslikult diskrimineerisid ainult kestust, ainult helikõrguse muutust ja kestuse + helikõrguse muutust. Selgus, et muusikud suudavad oluliselt paremini eristada nii keelelisi kui ka mittekeelelisi stiimuleid kõigi kolme tingimuse puhul võrreldes mittemuusikutega. Antud uuringu tulemus viitab sellele, et musikaalsusel on positiivne mõju keeletajule.

Märksõnad: tonaalne keel, helikõrguse tajumine, muusikaline treening, AX-i eksperiment

Introduction

There has been much research recently focusing on the connections between musical training and language perception. It has been revealed that some parts of the brain activate similarly with music and language. There is a common interaction between musical and linguistic dimensions of sung words, mostly within the identified brain networks (Schön et al., 2010).

It is important to know the connections between language and music processing to identify better how the human brain processes information. More importantly, it would help to find better ways to make language learning and comprehension more effective.

Around 70% of the world's languages are tonal, i.e., they use pitch to discriminate words' meanings (Yip, 2002). Mandarin Chinese (Mandarin or Chinese hereafter) is a tonal language that uses pitch variation to differentiate between words and deliver their meanings (Li et al., 2021). The identification of Mandarin tones is an important aspect of language communication and learning in Chinese-speaking societies (Alexander et al., 2005). Many studies suggest that the ability to identify Mandarin tones is not equal among non-native listeners and may vary depending on factors such as musical knowledge (Gottfried, 2007).

Studies have examined the musicality effect on the perception of Chinese tone among native Chinese speakers. In one study, Wu and colleagues (2015) compared the tone recognition performance of Mandarin musicians and non-musicians, revealing that native musicians have better sensitivity within phonemic pitch space and performed better in identifying lexical tones of Mandarin than native non-musicians. Another study on the perception of Mandarin tones in native musicians and non-musicians found that pitch processing plays a very important role in understanding the relationship between music and language (Chen et al., 2016). In addition, Lee (2017) investigated native Mandarin musicians and non-musicians living in the United States and found that musicians were better than non-musicians at identifying the pitch contour of Mandarin tones. Together, these results suggest that musical training may enhance tonal perception abilities among native speakers.

For non-native speakers of tonal languages, it is important to consider diverse factors that may impact their ability to accurately identify and produce tones (Chen et al., 2006). Non-native speakers need extensive exposure to tone perception and practice to develop accurate production skills (Perrachione et al., 2007). Chinese as a tonal language is challenging for non-natives to learn due to the requirement of distinguishing between various tones that change the meanings of the word in the language (Kusters, 2003). Studies have shown that non-native Chinese speakers tend to struggle with the production and perception of tones due to their unfamiliarity with tonal languages in their native language (Spencer et al., 2015). Tone perception and production are especially difficult for adult learners of Chinese since the processing of pitch in the human brain depends on language experience (Krishnan et al., 2005).

It has been shown that pitch processing is affected by the context of long-term experience such as musical training (Chandrasekaran et al., 2009). Even though the non-native subjects had no prior experience with tonal language, the musicians among them were more successful in discriminating tonal cues. Data suggested that non-native participants had more representations of pitch-relevant information thanks to the musical experience (Chandrasekaran et al., 2009). In addition, it was discovered that discrimination accuracy among musicians was much dependent on acoustic input. Difference in musicians and non-musicians perception decreased as the acoustic input was reduced (Han et al., 2019). Similar experiment was conducted by Lee and Hung (2008) where it was investigated how non-native subjects with or without a musical background identified Mandarin tones. Given study further confirmed that subjects with musical background identify lexical tones better (Lee *&* Hung, 2008). Results showed that English-speaking musicians exhibited a significantly higher overall sensitivity than either English-speaking non-musicians or Mandarin-speaking nonmusicians (Zhao & Kuhl, 2015).

Unlike most tonal and non-tonal languages, Estonian is a quantity language that has both a primary duration cue and a secondary pitch cue in its phonetic system (Lippus et al., 2009). The meaning of the word derives from the stressed vowel, syllable-medial consonants or the combination of the two (Lippus, 2012). In the Estonian three-way quantity, words vary between short (Q1), long (Q2), and overlong (Q3) quantity degrees. An example of the three-way quantity is *sada* [sata] - ‘hundred’, *saada* [sa:ta] – ‘to send, and *saada* [sa::ta] - ‘to get’ (Lippus et al., 2009). Vowel quantity carries semantic information that is needed for word comprehension in Estonian language and other quantity languages (Milovanov et al., 2009). As shown by Lippus et al. (2009), pitch is an important cue for Estonian native speakers to discriminate between long and overlong quantities.

In this paper, I am asking whether musical experience among native speakers of a quantity language like Estonian enhances the perception of Chinese. I will examine both the duration and pitch (tonal) information in the Chinese language because these are the two features in the Estonian language. Non-linguistic stimuli (pure tones) will also be included in the experiment. In general, I expect musicians to be more successful than non-musicians in the discrimination task given their long-term musical training. Specifically, I have the following hypotheses:

H1. The musicians will be more successful than non-musicians in perceiving both the linguistic (word) stimuli and the non-linguistic (pure tone) stimuli.

H2. The advantage of musicians over non-musicians is greater in non-linguistic (pure tone) stimuli than linguistic (word) stimuli.

Method

Participants

The sample consisted of 46 test subjects, of whom 23 were musicians and 23 non-musicians. The non-musicians were selected from a larger pool of subjects of another study (Lyu et al., 2023) and matched to the musicians with age and gender. All 46 participants spoke Estonian as their first language and had no formal experience with tonal languages. The musicians included 14 females (mean age=22, SD=2.05, min=19, max=26) and 9 males (mean age=23, SD=2.62, min=19, max=26). The non-musicians included 14 females (mean age=21, SD=1.69, min=19, max=24) and 9 males (mean age=22, SD=2.92, min=18, max=26).

Participants' previous musical experience was collected to determine their eligibility for the experiment. Musicians were required to have received more than seven years of formal musical training outside of school activities and to have been practicing at least once a week leading up to the study. Non-musicians had no self-reported prior musician training.

The study was approved by the Research Ethics Committee of the University of Tartu. Subjects joined the study voluntarily and could withdraw at any moment. The experiment paradigms were non-invasive. All the participants signed an informed consent form before any of the tests and received a gift card as compensation after the experiment.

Stimuli

The linguistic stimulus was the Chinese word JIDI where the pitch and length of the first vowel were adjusted. JIDI, depending on the pitch of the first syllable, has different meanings. In this experiment, the stimuli were tone 1 JIDI, i.e., *ji1d4* ‘base,’ and tone 2 JIDI, *ji2di4* ‘polar area.’ The first syllables of the two words were different, but the second syllable had the same tone 4. The two base words *ji1di4* and *ji2di4* were recorded by a native female speaker of Mandarin in a quiet room using the software Praat (Boersma, 2001) with a sampling frequency of 44100 Hz and then resynthesized in the same software. The duration of the first vowel was manipulated as either short or long, resulting in four different variants of the word JIDI in total.

As shown in Table 1 and Figure 1, stimulus T1_150 had a pitch that starts high and lowers. T1_250 had the same pitch, but the length of the first vowel was 250 milliseconds compared to T1_150 where it was 150 milliseconds. Stimulus T2_150 had a pitch that started low and rose. T2_150's first vowel was 150 milliseconds long, while T2_250's first vowel was 250 milliseconds long.

Table 1

Parameters of stimuli JIDI

Stimulus	Consonant 1	Vowel 1	Consonant 2	Vowel 2
	J	I	D	I
T1_150	90 ms	150 ms	40 ms	240 ms
T1_250	90 ms	250 ms	40 ms	240 ms
T2_150	90 ms	150 ms	40 ms	240 ms
T2_250	90 ms	250 ms	40 ms	240 ms

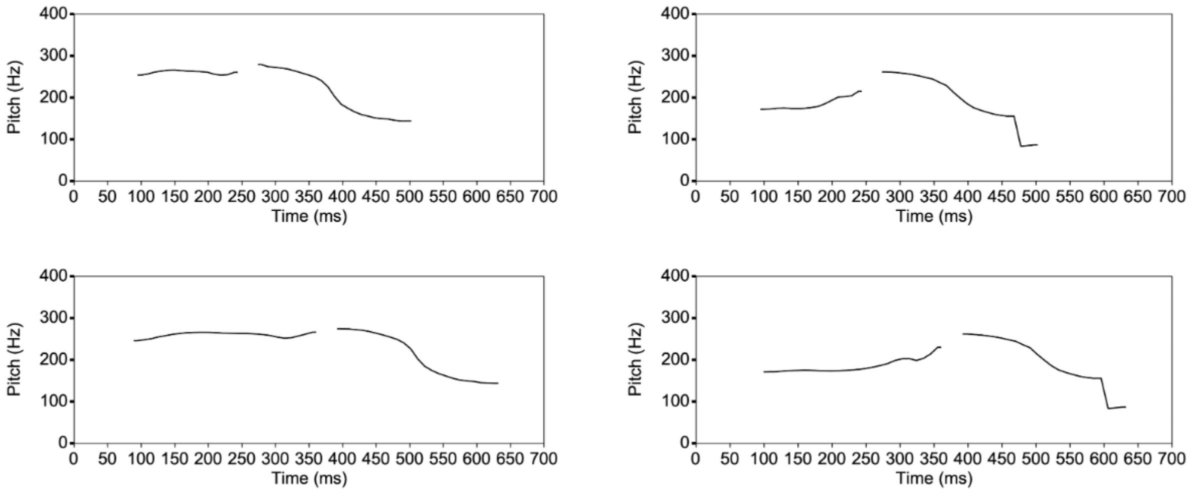

Figure 1. Illustrations of the stimuli pitch contours. On the left are the pitch contours of stimulus T1_150 (top) and T1_250 (bottom). On the right are the pitch contours of stimulus T2_150 (top) and T2_250 (bottom).

Non-linguistic pure tones were created on the basis of the pitch of the word stimuli. Their parameters were the same as the JIDI word stimuli. The pure tone stimuli were created by extracting the pitch contour from each of the word stimuli and generating a sine wave from the extracted pitch contour using Praat (Boersma, 2001). The pure tone resembled the physical characteristics of the corresponding word stimuli but did not carry any consonants or vowels. In total, in the current study, there were four versions of JIDI (linguistic) stimuli and four different kinds of JIDI pure tone (non-linguistic) stimuli.

Procedure

Participants received a link to a background questionnaire and were asked to fill it out before arriving at the lab. Upon arrival at the lab, each participant's hearing ability was first measured through audiometry. Subsequently, an electroencephalogram (EEG) experiment and a behavioral AX experiment were conducted. These experiments were conducted in a quiet, dimmed and electrically shielded room. The entire process took approximately 2.5 hours. Only the AX results were analyzed for this paper.

AX experiment was run on the E-prime 2 program (Psychology Software Tools, Pittsburgh, PA) and its purpose was to register how subjects differentiate given stimuli. The participants were played two audio files in a row/in pairs through earphones with a fixed stimulus interval of 300 milliseconds. The participants were asked to then decide whether two heard audio files were the same or different after hearing the two audios. They chose by pressing F for “same” and J for “different” on the keyboard. The time for making the response was limited to 1000 milliseconds. Subjects had the chance to do ten practice trials at the beginning of the experiment.

From the four versions of stimuli (as presented in Table 1), 4 same pairs and 12 different pairs were constructed. Same pairs consisted of the exact same versions of stimuli (e.g. T1_150-T1_150, T1_250-T1_250), and in the case of different pairs, the two stimuli were different (e.g. T1_150-T1_250, T1_250-T2_150). The different pairs were made of all possible combinations of different stimuli. The 12 different pairs of stimuli were repeated 5 times each and the 4 same pairs were repeated 15 times each, resulting in 120 pairs in total. Pure tone stimuli were constructed in the same way. Altogether there were 240 pairs of stimuli played during the experiment.

Audio files were played to the subjects in four blocks. During the first and third blocks, the participants listened to non-linguistic (pure tone) stimuli, while in the second and fourth blocks, they listened to linguistic (word) stimuli. In between every block, there was a short break, subjects could choose themselves when they wanted to move forward to the next block. Stimuli presentation within each block was pseudo-randomized. Participants went through 10 practice trials with the non-word “tata” at the beginning of the experiment to familiarize themselves with the procedure. The whole AX experiment took about 15 minutes to complete.

Results

Trials that subjects missed were excluded from the analysis. Altogether 5% of musicians’ and 2% out of non-musicians’ individual discrimination answers were excluded.

D-prime scores, which portrayed the sensitivity in discrimination in subjects, were used as dependent variables. D-primes were calculated based on the “hit” and “false alarm” rates. Hit rate was the number of times stimuli was correctly detected when it was present (subject chose “different” and the two stimuli played were indeed “different”). False alarm was the number of times stimuli was detected when it was not actually present (subject chose “different” but the two stimuli played were “same”). D-prime calculation was based on the instructions by Keating (2005) through the z-scores of hit (H) and false alarm (F) rates: d’ = z(H) - z(F).

Data was examined in JASP. Data was submitted to a repeated measures analysis of variance (ANOVA). Analysis was conducted separately for different conditions - duration, pitch and duration + pitch. Factor in all three ANOVAs was stimuli type and level 1 was word and level 2 pure tone stimuli. Between subjects factor was musicality. Descriptive statistics are provided in Table 2.

There was no significant stimuli type main effect - duration $p > 0.3$, pitch $p > 0.3$, duration + pitch $p > 0.3$. Musicality main effect was found in the analysis of all three conditions - duration $F(1, 44) = 7.42$, $p = 0.009$, pitch $F(1, 44) = 18.13$, $p < 0.001$, duration + pitch $F(1, 44) = 9.81$, $p = 0.003$. In all conditions, the musicians were more successful in discriminating the correct stimuli. There were no statistically significant interactions. Differences among musicians and non-musicians are visually represented in Figure 2.

Table 2

Descriptive statistics of d-prime

Condition	Musicality	Stimuli type	Mean	SD	N
Duration	Musicians	Word	3.88	0.89	23
		Pure tone	3.81	1.06	23
Pitch		Word	4.17	0.59	23
		Pure tone	4.23	0.47	23
Duration + pitch		Word	4.39	0.37	23
		Pure tone	4.36	0.33	23
Duration	Non-musicians	Word	3.13	0.99	23
		Pure tone	3.02	1.08	23
Pitch		Word	3.17	1.13	23
		Pure tone	3.33	1.03	23
Duration + pitch		Word	3.91	0.69	23
		Pure tone	3.81	0.85	23

Note. SD = standard deviation; N = number of subjects.

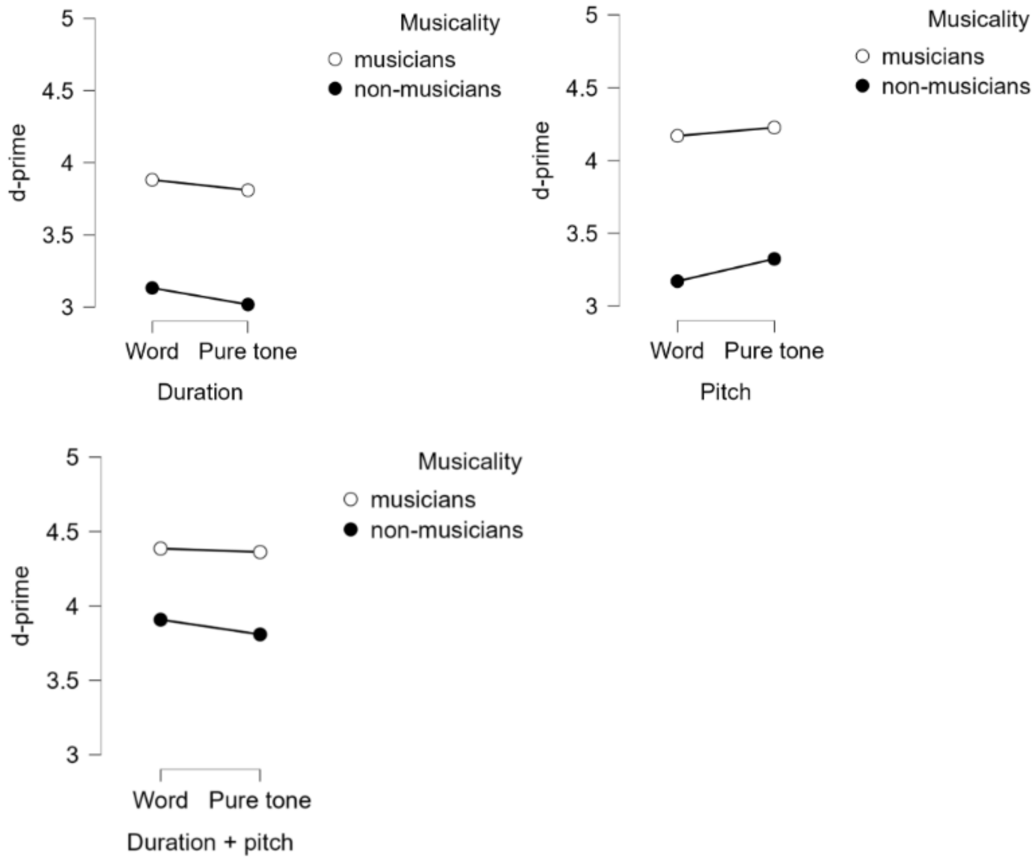

Figure 2. Representation of stimuli type identification among musicians and non-musicians.

Discussion

The aim of this paper is to examine the musicality effect on (tonal) language perception. First hypothesis stated that musicians would outperform non-musicians in perceiving both the Mandarin stimuli and their non-linguistic equivalents (i.e., pure tones). Second hypothesis stated that musicians will exceed (non-musicians) in discriminating non-linguistic stimuli more than in discriminating linguistic stimuli.

First proposed hypothesis (H1) was confirmed. It was found that Estonian musicians were more successful in discriminating both the Chinese linguistic and the non-linguistic stimuli (pure tones) than Estonian non-musicians in all three conditions. The finding confirms that musicality has an effect on language perception. Several previous studies have reached a similar conclusion among different native language speakers. Chandrasekaran and colleagues (2009) found that non-native musicians could discriminate tonal cues of a lexical language better than native and non-native non-musicians. Similarly, Lee and Hung (2008) results showed that musicians without prior tonal language experience were more successful in discriminating tones than non-musicians. Together with the previous studies, the present study suggests that long-term musical training accompanies an advantage for lexical language perception and identification.

Research has shown that music and speech share neural processing mechanisms which link musical and linguistic pitch processing (Cui & Kuang, 2019). It has been found that musical training can lead to significantly better auditory and enhanced musical abilities. Superior auditory competence is found to be one of the aspects that gives musicians the linguistic advantage (Musso et al., 2020) since it develops the recognition of specific sound components as well as their integration (Kyrtsoudi et al., 2023). Musicality is associated with increased pitch processing in speech, speech segmentation and second language learning (Cui & Kuang, 2019). Results of the current study support previous findings on music and language overlap.

While a number of papers (Alexander et al., 2005; Cui & Kuang, 2019) have focused on only the pitch aspect which is important both in musicality and processing of lexical language, the present study examines additional information like duration and duration + pitch in tonal language. Pitch is instrumental in Mandarin, duration in quantity language such as Estonian and duration + pitch is the combination of the two. The current manipulation of stimuli allows us to examine subjects' ability to discriminate different (familiar and less familiar) aspects of a language. It helps us correctly evaluate the importance of different qualities of language and speech perception. As seen in Figure 2, musicality effect was found among all these conditions. The present study added to the literature, which has mostly found the musicality effect based on pitch experiments, by examining the distinctive features of the native language the subject speaks. That gives us valuable insight into language differences and allows us to study it even more extensively.

Second hypothesis (H2) was not confirmed. It was expected that musicians' advantage over non-musicians is larger in discriminating non-linguistic stimuli than linguistic stimuli. Musical training is directly associated with identification and registration of tone difference. Non-linguistic stimuli seemed to be most similar to stimuli that a musician is exposed to on a daily basis. However, there were no significant differences in word and pure tone stimuli perception found. Musicians outperformed non-musicians in both word and pure tone conditions. It is possible that the general attributes of the stimuli overpowered the word and pure tone variative characteristics. Therefore, subjects perceived it similarly both when listening to linguistic and non-linguistic stimuli.

One limitation of current work is the method used for data analysis. Since the focus of the study is the musicality effect and the difference among the three conditions is not as important, I did not run a three-way ANOVA where condition was included as a fixed effect. With the current analysis, the three conditions (duration, pitch, duration + pitch) cannot be compared with each other because three separate ANOVAs were used to interpret the data. Therefore it is not possible to draw overall conclusions concerning the separate e.g pitch or duration discrimination abilities among subjects. ANOVA that includes the entire dataset could be used for more extensive analysis in the future.

Another limitation or aspect that could be improved in future research is the choice of stimuli. Current stimuli was based on Mandarin Chinese which belongs in the group of tonal languages. However, there are differences among distinct lexical languages. For instance, in Cantonese language there are six contrastive lexical tones (Mok et al., 2013) whereas in Mandarin Chinese there are four. Differences between the speakers of those languages have been found when it comes to language perception (Lee et al., 1996). With the help of additional tones as stimuli it would be possible to make further conclusions.

For future research, it is important to state that musical experience has many forms (e.g instrumental expertise, vocal expertise, difference in musical genres) which is why exploring different musical outputs and their connections with language perception could be very beneficial to the development of the field. Kyrtsoudi and colleagues (2023) conducted a study on the topic where they compared the auditory perception results with different musical specializations. They found that different musical specialities might predict different skills related to language perception (e.g frequency, rhythm discrimination).

There is proof that musicality and language processing are interrelated which is why further examining the bidirectional effect of music and language could be very beneficial to the field. The influence of tonal language background on musical perception has been studied. For example, a study found that regardless of having a musical background or not, native speakers of tonal languages had an advanced ability to discriminate musical melodies as compared to the speakers of non-tonal languages (Liu et al., 2023). Furthermore, Biedelman and colleagues sought to find the differences between musicians and Cantonese speakers. Results concluded that tonal language speakers outperformed English speaking non-musicians in musical and pitch perception. Results showed even better working memory capacity among musicians and tone language speakers compared to non-musicians (Bidelman et al., 2013). Studying the effect from both perspectives in the future would help us understand the specific connections better.

Conclusion

This study investigates connections between musical and linguistic processing. There are specific cues in different language groups which help derive the meaning of the word. Current work explored how Estonian musicians process linguistic cues in Mandarin as compared to Estonian non-musicians. Musicians were able to discriminate stimuli in a foreign language significantly better than non-musicians. Results of the current study confirmed that speech and music processing might occur in a common domain since the effect of musicality in language perception was strongly represented. Future research should consider testing the findings by using stimuli from different musical specialties and further examine the mutual impact of native tonal language and musicality.

References

Alexander, J. A., Wong, P. C. M., & Bradlow, A. R. (2005). Lexical tone perception in musicians and non-musicians. *Interspeech 2005*. ISCA. https://doi.org/10.21437/interspeech.2005-271

Bidelman, G. M., Hutka, S., & Moreno, S. (2013). Tone Language Speakers and Musicians Share Enhanced Perceptual and Cognitive Abilities for Musical Pitch: Evidence for Bidirectionality between the Domains of Language and Music. PLoS ONE, 8(4), Article e60676. https://doi.org/10.1371/journal.pone.0060676

Boersma, Paul (2001). Praat, a system for doing phonetics by computer. Glot International 5:9/10, 341-345.

Chandrasekaran, B., Krishnan, A., & Gandour, J. (2009). Relative influence of musical and linguistic experience on early cortical processing of pitch contours. *Brain and Language*, 108(1), 1–9. https://doi.org/10.1016/j.bandl.2008.02.001

Chen, A., Liu, L., & Kager, R. (2016). Cross-domain correlation in pitch perception, the influence of native language. *Language, Cognition and Neuroscience*, 31(6), 751–760. https://doi.org/10.1080/23273798.2016.1156715

Chen, S., Geluykens, R., & Choi, C. J. (2006). The importance of language in global teams: A linguistic perspective. *Management international review*, 46, 679-696. https://doi.org/10.1007/s11575-006-0122-6

Cui, A., & Kuang, J. (2019). The effects of musicality and language background on cue integration in pitch perception. *The Journal of the Acoustical Society of America*, 146(6), 4086–4096. https://doi.org/10.1121/1.5134442

Gottfried, T. L. (2007). Music and language learning. *In Language Experience in Second*

Language Speech Learning (pp. 221–237). John Benjamins Publishing Company. https://doi.org/10.1075/lllt.17.21got

Han, Y., Goudbeek, M., Mos, M., & Swerts, M. (2019). Mandarin Tone Identification by Tone-Naïve Musicians and Non-musicians in Auditory-Visual and Auditory-Only Conditions. *Frontiers in Communication*, 4. https://doi.org/10.3389/fcomm.2019.00070

Keating, P. (2005) D-prime (signal detection) analysis. UCLA Phonetics Lab statistics. http://phonetics.linguistics.ucla.edu/facilities/statistics/dprime.htm

Kyrtsoudi, M., Sidiras, C., Papadelis, G., & Iliadou, V. M. (2023). Auditory Processing in Musicians, a Cross-Sectional Study, as a Basis for Auditory Training Optimization. Healthcare, 11(14), 2027. https://doi.org/10.3390/healthcare11142027

Lee, C.-Y. (2017). Processing acoustic variability in lexical tone perception. In A. Lahiri & S. Kotzor (Eds.), *The Speech Processing Lexico*n. De Gruyter. https://doi.org/10.1515/9783110422658-007

Lee, C.-Y., & Hung, T.-H. (2008). Identification of Mandarin tones by English-speaking musicians and nonmusicians. The Journal of the Acoustical Society of America, 124(5), 3235–3248. https://doi.org/10.1121/1.2990713

Li, Y., Tang, C., Lu, J., Wu, J., & Chang, E. F. (2021). Human cortical encoding of pitch in tonal and non-tonal languages. *Nature Communications*, 12(1). https://doi.org/10.1038/s41467-021-21430-x

Lee, Y.-S., Vakoch, D. A., & Wurm, L. H. (1996). Tone perception in Cantonese and Mandarin: A cross-linguistic comparison. *Journal of Psycholinguistic Research*, 25(5), 527–542. https://doi.org/10.1007/bf01758181

Liu, J., Hilton, C. B., Bergelson, E., & Mehr, S. A. (2023). Language experience predicts music processing in a half-million speakers of fifty-four languages. *Current Biology*. https://doi.org/10.1016/j.cub.2023.03.067

Lippus, P. (2012). 5. acoustic features of quantity in early recordings of Estonian. *Encapsulated Voices*, 85–98. https://doi.org/10.7788/boehlau.9783412215095.85

Lippus, P., Pajusalu, K., & Allik, J. (2009). The tonal component of Estonian quantity in native and non-native perception. *Journal of Phonetic*s, 37(4), 388–396. https://doi.org/10.1016/j.wocn.2009.07.002

Lyu, S., Põldver, N., Kask, L., Wang, L., & Kreegipuu, K. (2023). Native language background affects the perception of duration and pitch [Manuscript under review].

McDermott, J. H., & Oxenham, A. J. (2008). Music perception, pitch, and the auditory system. *Current Opinion in Neurobiology*, 18(4), 452–463. https://doi.org/10.1016/j.conb.2008.09.005

Milovanov, R., Huotilainen, M., Esquef, P. A. A., Alku, P., Välimäki, V., & Tervaniemi, M. (2009). The role of musical aptitude and language skills in preattentive duration processing in school-aged children. *Neuroscience Letters*, 460(2), 161–165. https://doi.org/10.1016/j.neulet.2009.05.063

Mok, P. P. K., Zuo, D., & Wong, P. W. Y. (2013). Production and perception of a sound change in progress: Tone merging in Hong Kong Cantonese. *Language Variation and Change*, 25(3), 341–370. https://doi.org/10.1017/s0954394513000161

Musso, M., Fürniss, H., Glauche, V., Urbach, H., Weiller, C., & Rijntjes, M. (2020). Musicians use speech-specific areas when processing tones: The key to their superior linguistic competence? *Behavioural Brain Research*, 390, 112662. https://doi.org/10.1016/j.bbr.2020.112662

Patel, A. D. (2010). *Music, language, and the brain.* Oxford university press.

Perrachione, T. K., & Wong, P. C. M. (2007). Learning to recognize speakers of a non-native language: Implications for the functional organization of human auditory cortex. *Neuropsychologia*, 45(8), 1899–1910. https://doi.org/10.1016/j.neuropsychologia.2006.11.015

Schneider, W., Eschman, A., and Zuccolotto, A. (2012). E-Prime User's Guide. Pittsburgh: Psychology Software Tools, Inc

So, C. K., & Best, C. T. (2010). Cross-language Perception of Non-native Tonal Contrasts: Effects of Native Phonological and Phonetic Influences. *Language and Speech*, 53(2), 273–293. https://doi.org/10.1177/0023830909357156

Wu, H., Ma, X., Zhang, L., Liu, Y., Zhang, Y., & Shu, H. (2015). Musical experience modulates categorical perception of lexical tones in native Chinese speakers. *Frontiers in Psychology*, 06. https://doi.org/10.3389/fpsyg.2015.00436

Yip, M. (2012). *Tone*. Cambridge University Press.

Zhao, T. C., & Kuhl, P. K. (2015). Effect of musical experience on learning lexical tone categories. *The Journal of the Acoustical Society of America*, 137(3), 1452–1463. https://doi.org/10.1121/1.4913457

Käesolevaga kinnitan, et olen korrektselt viidanud kõigile oma töös kasutatud teiste autorite poolt loodud kirjalikele töödele, lausetele, mõtetele, ideedele või andmetele.

Olen nõus oma töö avaldamisega Tartu Ülikooli digitaalarhiivis DSpace.

Hanna Pria Hulkko