



# Improved tactile frequency discrimination in musicians

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## Abstract

Music practice is a multisensory training that is of great interest to neuroscientists because of its implications for neural plasticity. Music-related modulation of sensory systems has been observed in neuroimaging data, and has been supported by results in behavioral tasks. Some studies have shown that musicians react faster than non-musicians to visual, tactile and auditory stimuli. Behavioral enhancement in more complex tasks has received considerably less attention in musicians. This study aims to investigate unisensory and multisensory discrimination capabilities in musicians. More specifically, the goal of this study is to examine auditory, tactile and auditory-tactile discrimination in musicians. The literature suggesting better auditory and auditory-tactile discrimination in musicians is scarce, and no study to date has examined pure tactile discrimination capabilities in musicians. A two-alternative forced-choice frequency discrimination task was used in this experiment. The task was inspired by musical production, and participants were asked to identify whether a frequency was the same as or different than a standard stimulus of 160 Hz in three conditions: auditory only, auditory-tactile only and tactile only. Three waveforms were used to replicate the variability of pitch that can be found in music. Stimuli were presented through headphones for auditory stimulation and a glove with haptic audio exciters for tactile stimulation. Results suggest that musicians have lower discrimination thresholds than non-musicians for auditory-only and auditory-tactile conditions for all waveforms. The results also revealed that musicians have lower discrimination thresholds than non-musicians in the tactile condition for sine and square waveforms. Taken together, these results support the hypothesis that musical training can lead to better unisensory tactile discrimination which is in itself a new and major finding.

**Keywords** Music · Tactile · Multisensory training · Brain plasticity

## Introduction

Musical training is known to enhance multisensory integration (Herholz and Zatorre 2012) and to alter the anatomy of multisensory structures (for a review, see Münte et al. 2002). In link with these cortical changes, modulations in the sensory system in musicians have also been supported by results in behavioral tasks. For example, it has been shown that musicians react faster than non-musicians to visual (Anatürk and Jentsch 2015; Chang et al. 2014), tactile (Landry and Champoux 2017) and auditory stimuli (Landry and Champoux 2017; Strait et al. 2010). A study from our group used

the race model inequality analysis (Raab 1962) in an auditory and tactile detection task and demonstrated that the gain from adding tactile information to auditory inputs was greater in musicians than in non-musicians (Landry and Champoux 2017).

Behavioral enhancement in more complex tasks has received considerably less attention in musicians. Spiegel and Watson (1984) and Micheyl et al. (2006) suggested that musicians have better auditory frequency discrimination thresholds compared to non-musicians, and this appeared to be correlated with years of musical practice (or training) (Kishon-Rabin et al. 2001). These results suggest that auditory frequency discrimination is enhanced in musicians. However, unisensory frequency discrimination capabilities have not been thoroughly explored so far. However, a few studies suggest that such enhancement of the discrimination processing might also extend to multisensory processing. Young et al. (2017) used a simple two-alternative forced-choice task in which participants had to decide whether two

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stimuli were the same or different while hearing or hearing and feeling those stimuli with the addition of a vibrotactile glove. Three different kinds of waveforms (sine wave, sawtooth, and square) were presented to evaluate musical vs. non-musical capabilities more independently. The authors showed that adding tactile stimulation significantly improved frequency discrimination in musicians compared to non-musicians for both pure tones (sine wave) and more complex waveforms (sawtooth and square waves). The results are important as they suggest that musicians could make use of the tactile modality for perceiving music, which may have implications for musical practice. However, it is still not clear whether the discrimination capabilities observed in musicians result from an enhanced ability to integrate multisensory information per se, or an enhanced ability to discriminate auditory and tactile information separately, which would necessarily lead to better perception when both unisensory modalities are made available.

The goal of this study is to investigate unisensory and multisensory discrimination capabilities in musicians. More specifically, we aim to examine auditory, tactile and auditory-tactile discrimination in musicians using the procedure developed by Young et al. (2017). Besides being the first to examine tactile discrimination capabilities in musicians, the results will add to the scarce literature suggesting better auditory and auditory-tactile discrimination in musicians. A positive result in the tactile-only condition could indicate that the multisensory training that musicians experience has a greater impact on the development of sensory modalities than what was originally assumed. The data could also highlight the need to develop protocols to examine unisensory and multisensory discrimination processing separately in this population.

## Method

### Participants

Fifteen professional musicians (six women, nine men, average age = 29.5 years, age range 21–59 years) and 15 non-musicians (six women, nine men, average age = 33.6 years, age range 22–62 years) participated in the study (no significant difference between groups for age  $p=0.412$ ). Only participants with less than 1 year of musical training were recruited for the control group. All musicians were professionals since they were studying at a university level in music or working in the music field. Musicians reported piano ( $n=8$ ), guitar ( $n=2$ ), violin ( $n=1$ ), percussion ( $n=1$ ), flute ( $n=1$ ), oboe ( $n=1$ ) and trumpet ( $n=1$ ). They also reported playing only one instrument ( $n=3$ ), playing two instruments ( $n=2$ ) and playing more than two instruments ( $n=10$ ). The average age of learning of the first instrument

was 7 years. The average number of years of active practice of music was 20.2 years. All participants reported have good hearing, vision, no neurological, tactile or other medical condition. A standard audiological procedure was used to ensure that participants had normal hearing. For both groups, pure-tone detection thresholds at octave frequencies ranging from 250 to 4000 kHz were within normal limits in both ears. Hearing thresholds were determined via an audiometer (Astera, GN Otometrics, Denmark). The Research Committee for Health Sciences of the University of Montreal and the Center for Interdisciplinary Research in Rehabilitation of Greater Montreal approved all procedures, and each participant provided written informed consent. All experiments were performed in accordance with relevant guidelines and regulations.

### Stimuli and procedure

Method and stimuli were the same as in Young et al. (2017). All stimuli were created via Audacity® Version 2.3.0 (Audacity Team 2019). Basically, these corresponded to sinusoidal, square and sawtooth complex waves whose spectrum is infinite and whose fundamental frequency is 160 Hz. Stimuli were presented in pair, one stimulus was an unmodified tone (160 Hz) and the other one was shifted in frequency. Stimulus pairs varied in frequency by  $\pm 0; 0.25; 0.5; 0.8; 1; 1.5; 2; 3; 4; 6; 8; 12; 16; 20; 24; 36; 48$  Hz. Wave types were not directly compared to each other within trials (two compared stimuli both had the same wave type, e.g., 160–172 Hz sinusoidal). Each pair of stimuli represented a type of waveforms and were presented randomly twice in a block. Each block was computed by the software PsyScope 1.2.5 (Cohen 1993) on a Mac computer that was programmed to randomize the presentation of all pair of stimuli.

The purpose of using three types of waveforms was to simulate different musical timbres. Even if a piano and a violin produce a note having the same fundamental frequency, it is possible to determine which instrument produces which note, because they differ by timbre. Using sinusoidal waves (no harmonics), sawtooth waves (odd harmonics) and square waves (even and odd harmonics), the task becomes more representative of the frequency discrimination that occurs during music listening, representing the perception of three artificial musical instruments.

Participants were seated in a soundproof room and stimuli were presented via headphones (TDH-39, Diatec, Canada) for the auditory-only condition, via both headphones and a vibrating glove for the auditory-tactile condition, and only via the vibrating glove device for the tactile-only condition. The masking procedure during tactile stimulation was the same as used previously in our laboratory (see Landry et al. 2013; Landry et al. 2014). During the tactile-only condition, white noise was presented via attenuating circumaural

headphones (10 S/DC, David Clark, Worcester, MA, USA) and the participant wore earplugs. A preliminary study was done to make sure that detection via bone-conduction would not be possible with this noise level.

The vibrating glove was a replication of the glove used by Young et al. (2017), equipped with six independent audio-haptic voice-coil exciters. The voice-coil transducers (TEAX14C02-8 Compact Audio Exciter) had a diameter of 14 mm and were designed to deliver vibrotactile output at frequencies the hand is most sensitive to. Stimuli were sent via a Dayton Audio DTA3116S Class D Micro Mini Amplifier (2 × 15 W), linked via an audio cable to the software Psyscope 1.2.5 (Cohen 1993) on a Mac computer.

The participant verbally indicated whether the perceived intensity of the different tactile stimuli was the same while performing the task of discriminating two frequency stimuli during a trial practice period (ten trials). The task was divided into three blocks of 80 trials. The task was repeated three times (auditory, auditory-tactile and tactile). A constant stimuli procedure was used in this experiment to compute threshold and each  $\Delta F$  was presented four times during each stimulation condition. The number of trials was based on Young et al. (2017) who used three trials per intervals. One trial per intervals was added to increase the number of trials, taking into account that increasing more would lead to fatigue for participants and create a new bias. The method of constant stimuli used with 100 trials or less is as efficient and less biased than the adaptative method (Simpson 1988).

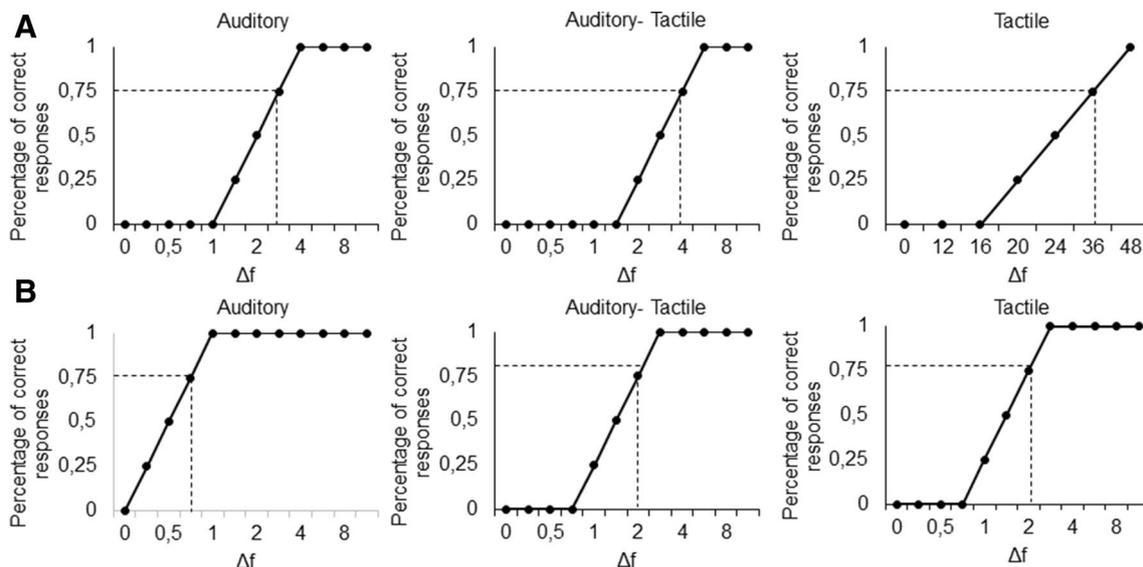
In each trial, two stimuli that varied in frequency were presented to the participant. Each stimulus had a duration of 2 s and they were separated in time by a pause

of 1 s. The participant had to identify whether the two stimuli presented were the same or different. To answer, the participant made a selection on the screen using the computer mouse.

### Analysis

The just noticeable difference was calculated for all conditions (see Fig. 1 for a typical case analysis for each group): the difference between the reference frequency (160 Hz) and the frequency where the participant had a recognition score of 75% (above and under 160 Hz taken together) was used as the threshold of recognition ( $\Delta F$ ). Unspeeded reaction times were measured during the experiment via Psyscope software. A multivariate analysis of variance was used to compare the threshold of recognition ( $\Delta F$ ) between groups. Type of waves (sinus, square, saw) and modalities (auditory-only, auditory-tactile, tactile-only) were the dependent variables and group was the independent variable. Another MANOVA with the same variables was used to compare reaction times.

As explained by Gescheider (2013), the 2AFC task is not contaminated by fluctuations in the criterion. Nevertheless, response bias towards one or more observations may still exist. This type of design, however, does not guarantee a complete absence of bias. To control for the sensitivity bias, participants data were verified to ensure that there was no false-positive. If a participant had one false-positive or more (answered “different”, when stimuli were the same), he was eliminated from the study. No participant was eliminated based on that criteria.



**Fig. 1** Typical psychometric function in response to sine waveform in a control (a) and a musician (b) in the three experimental conditions (auditory, auditory-tactile and tactile)

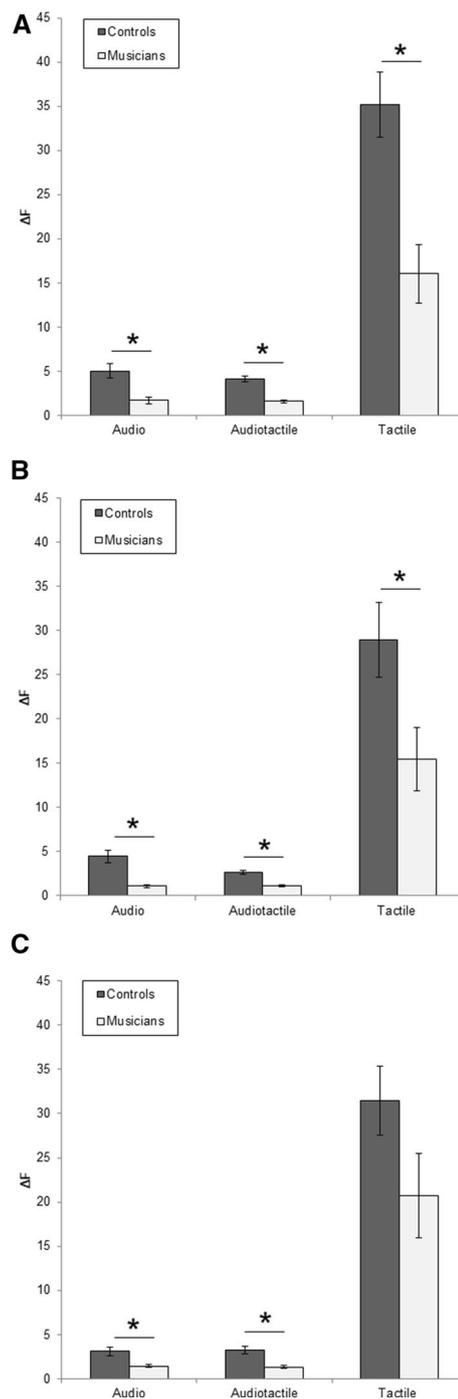
## Results

Figure 2 displays the mean thresholds of recognition for auditory, auditory-tactile and tactile conditions for sine waves (Fig. 2a), square waves (Fig. 2b) and sawtooth waves (Fig. 2c). Results from the one-way MANOVA revealed significant differences for  $\Delta F$  for every condition except for the tactile condition with sawtooth waveform stimulation. As shown in Fig. 2, there was a statistically significant difference in conditions based on the group [ $F(9, 20) = 9.534, p < 0.001$ ; Wilk's  $\Lambda = 0.450$ , partial  $\eta^2 = 0.811$ ]. Furthermore, group has a statistically significant effect in the following conditions: sinusoid auditory [ $F(1, 28) = 15.085; p = 0.001$ ; partial  $\eta^2 = 0.35$ ], sinusoid auditory-tactile [ $F(1, 28) = 41.902; p < 0.001$ ; partial  $\eta^2 = 0.60$ ], sinusoid tactile [ $F(1, 28) = 15.893; p < 0.001$ ; partial  $\eta^2 = 0.36$ ], square auditory [ $F(1, 28) = 23.745; p < 0.001$ ; partial  $\eta^2 = 0.46$ ], square auditory-tactile [ $F(1, 28) = 40.113; p < 0.001$ ; partial  $\eta^2 = 0.59$ ], square tactile [ $F(1, 28) = 6.322; p = 0.018$ ; partial  $\eta^2 = 0.18$ ], and sawtooth auditory [ $F(1, 28) = 11.648; p = 0.002$ ; partial  $\eta^2 = 0.30$ ], sawtooth auditory-tactile [ $F(1, 28) = 19.349; p < 0.001$ ; partial  $\eta^2 = 0.41$ ], but not on sawtooth tactile [ $F(1, 28) = 3.258; p = 0.082$ ; partial  $\eta^2 = 0.10$ ]. The multivariate analysis of variance was not significant for reaction times [ $F(9, 16) = 1.341, p = 0.292$  Wilk's  $\Lambda = 0.570$ , partial  $\eta^2 = 0.430$ ]. In every stimulation condition, average percentage of difference in the thresholds were higher in controls compare to musicians for auditory (sinus: 66.6%; saw: 54.6%; square: 75.1%), auditory-tactile (sinus: 61.7%; saw: 60.2%; square: 56.5%) and tactile (sinus: 54.5%; saw: 34.1%; square: 46.7%).

To provide an estimation of the multisensory benefits compared to unimodal conditions, the gain from adding tactile stimulation to auditory stimulation was calculated. The formula proposed by Rouger et al. (2007) was used to calculate the gain for each participants: (auditory-tactile score – auditory score)/(100 – auditory score). The results showed that there was no gain for musicians (average 0%) in every waveform conditions. For control, there was a gain of 1% for sinus waveform and 2% for square waveform, no gain was found for saw waveform.

## Discussion

The main goal of this study was to evaluate the effect of musical training on frequency discrimination of auditory-only, auditory-tactile and tactile-only stimuli. We found a significant difference between groups for auditory, tactile, and auditory-tactile stimulation where musicians had



**Fig. 2** Frequency discrimination threshold average for non-musicians and musicians for the three test conditions (auditory, auditory-tactile, tactile) for **a** sine waveform stimuli. **b** Square waveform stimuli. **c** Sawtooth waveform stimuli. \* $p < 0.05$

smaller discrimination threshold than non-musicians. For the auditory-only condition, these results are consistent with previous studies that have shown that musicians have better performance on simple frequency discrimination tasks (Spiegel and Watson 1984; Kishon-Rabin et al. 2001;

Micheyl et al. 2006). Other studies investigating spectral aspects of music are using more complex stimuli such as chords or musical instrument samples to show that musicians have superior pitch discrimination or timbre discrimination. For example, Tervaniemi et al. (2005) have shown that musicians can detect pitch changes faster and more accurately compared to non-musicians; these behavioral differences are accompanied by larger amplitude N2b and P3 responses. Those results combined with our results support the hypothesis that musicians have improved performance for unisensory abilities and, furthermore, support the increased auditory cortical representation in musicians found by imaging studies (Pantev et al. 1998). Our results in the auditory-tactile condition are also consistent with Young et al. (2017), who used the same device to test frequency discrimination thresholds. Musicians and non-musicians had better discrimination when stimuli were presented in both modalities, but musicians outperformed them in the auditory-tactile condition. Even though musicians outperformed controls in the auditory-tactile condition, no gain was measured for musicians compared to a weak gain measured in controls. This can be explained by a ceiling effect. It is well-known that auditory musical abilities in general in musicians are improved (for a review see Kraus and Chandrasekaran 2010). This can explain why controls were able to use information from tactile stimulation to improve their performance while musicians were already performing too well to improve more. These results are consistent with the fact that in the auditory-only condition, musicians had a much better performance than controls. Finally, the fact that control were able to use output from tactile stimulation to improve their performance in a frequency discrimination is it itself an interesting new finding. The exact neural correlates for the reported frequency discrimination task used here are still open for investigation, since no imaging studies to date have used a protocol that includes haptic stimulation similar to ours. Further studies should use a more sensitive task to avoid the possible ceiling effect found in this study.

The present study was the first to investigate tactile-only discrimination of frequency in musicians. This study revealed that musicians are better in the tactile-only condition, which is in itself a new and major finding. No study to date has shown that the frequency discrimination threshold for simple tactile stimuli is improved in musicians. These results are consistent with the previous investigation, suggesting that musical training enhances performance in less complex tasks, such as stimulus detection (Landry and Champoux 2017). The present study adds to the existing literature on unisensory processing in musicians by suggesting for the first time that long-term musical training can also improve tactile performance in more complex tasks.

Results for reaction times showed no significant differences between groups. Previous studies have revealed that musicians react faster than non-musicians to visual stimuli (Anatürk and Jentzsch 2015; Chang et al. 2014), tactile stimuli (Landry and Champoux 2017) and auditory stimuli (Landry and Champoux 2017; Strait et al. 2010). All these studies used a simple reaction time protocol to report when a stimulus was detected by the participant. The lack of difference between musicians and non-musicians for reaction time may be explained by the complexity of the task. Further studies are needed to investigate reaction time in more complex tasks for auditory and tactile stimuli.

No difference was found between musicians and non-musicians for the tactile-only condition for sawtooth waveform. The sawtooth waveform sound contains both even and odd harmonics of the fundamental frequency, hence it is closer to music compared to the other two stimuli: square waveform (odd harmonics) and sine waveform (pure tone). Because most people have experience discriminating between frequencies while listening to music, this could explain the non-significant difference in performance between musicians and non-musicians. Further studies are needed to validate this hypothesis.

It is well-known that the type of instrument played can influence cortical plasticity. For example, Elbert et al. (1995) found that in a group of expert string instrumentalists, the region of the somatosensory cortex that represents input from the left hand was significantly more responsive to tactile stimulation than in non-musicians. Also, Gruhn (2002) found that it is easier to learn in early childhood than in the later years. Researchers suggest that up to 7 years of age there is a sensitive period, beyond which music-induced structural changes and learning effects are less pronounced (for a review see Habib and Besson 2009). Furthermore, Gaser and Schlaug (2003) have demonstrated that the amount of gray matter differs between professional musicians, amateur musicians and non-musicians in the motor, auditory and visual-spatial regions. The more a musician was trained, the larger was the quantity of gray matter. The homogeneity of the group of musicians in this study did not allow us to incorporate covariates such as the degree of musician training, the type of instrument played, the type of music played, the age of learning of the first instrument or the number of hours of practice. The musicians who participated in this study were all professional musicians, most of them played piano as a principal instrument and started to play music around 7 years of age. Further study should investigate if these characteristics influence tactile frequency discrimination in musicians.

In conclusion, this study provides the first investigation of a frequency discrimination task in musicians in the tactile-only modality; results revealed a smaller threshold compared to controls. This major new finding suggests that

not only are multisensory abilities improved in musicians, as found in past studies, but that non-auditory unisensory abilities are also improved. The precise nature and cause of this enhanced non-auditory discrimination in musicians will need to be documented in further research. Also, various types of musicians should be investigated in the future to investigate the influence of the type of musical instrument played, the number of instruments played, the age of learning the first instrument, the number of hours of practice and all other characteristics that have been suggested to influence musicians' performance in the past.

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