Auditory cortical activity response to frequency change is altered by long-term musical training

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INTRODUCTION

- The ability to detect frequency variation which is related to pitch perception is a fundamental skill necessary for speech perception.
- Pitch processing is even more crucial for understanding sounds under adverse listening conditions such as background noise.
- It is known that musical expertise is associated with a range of auditory perceptual skills, including discrimination frequency change.
- It suggests the neural encoding of spectral features can be enhanced by musical training.
- We hypothesized that the cortical activity to frequency change is more enhanced in musicians compared to non-musicians.
- We also predicted that musicians reveal better noise perception than non-musicians.

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METHODS

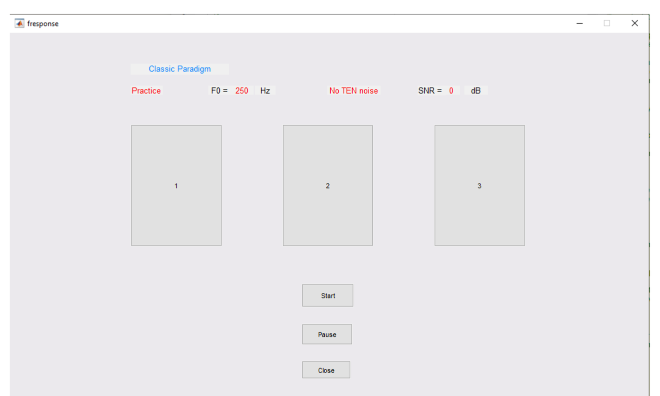
Subjects

- **13 musicians (mean age: 27.1 $\pm$ 5.0 yrs, 6 male)**
  - have received professional musical training over 10 years regularly.
  - have trained at least three times a week during the training period.
  - instruments: vocal, piano, drum, haegeum, guitar, and violin.
- **11 non-musicians (mean age: 26.8 $\pm$ 5.31 yrs, 6 male)**

Psychoacoustics: Frequency discrimination task

- standard adaptive, three-interval, three-alternative, forced-choice
- Two of three stimuli contained base frequency pure tones, while the remaining one had a pure tone with a higher frequency change.
- Two-down, one-up procedure to detect the threshold

in noise condition with 4 types of background threshold-equalizing noise (TEN) : no TEN and +5, 0, and -5 dB signal to noise ratio TEN.



Stimuli

- Continuous stimuli consisted of frequency change stimuli followed by pure tones with base frequency 250 or 4000 Hz
- Frequency change of 10%, 25%, or 50% lasting 400 ms
- The order of frequency change was randomly determined.
- The duration of base frequency pure tones varied from 1.6 to 2.2 s to prevent anticipating the point where the frequency change occurred.

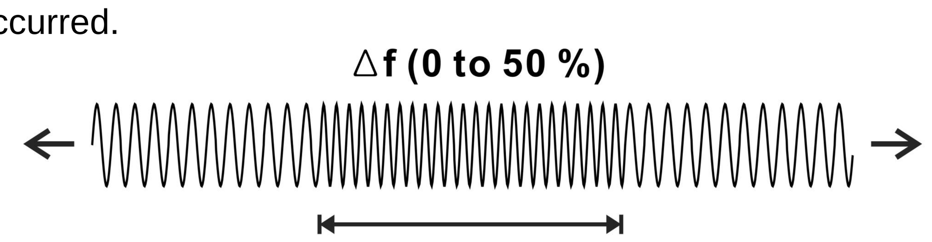


Figure 1. Schematic representation of frequency change stimulus.

Electroencephalogram (EEG) recording

- Recorded from 64 scalp electrode cap (Brain Vision actiChamp).
- A minimum of 100 trials for each frequency change was presented in two blocks.
- Subjects were seated in a comfortable reclining chair and watched a close-captioned movie of their choice while the frequency change stimuli were presented through two channel speakers.
- The total EEG recording time was approximately 30 mins.

EEG data analysis

- N1 and P2 amplitudes and latencies were measured from fronto-central electrodes (see figure 2) and analyzed as a function of frequency change for musicians and non-musicians.

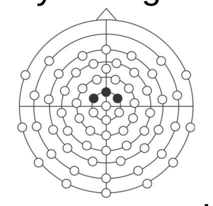


Figure 2. An equidistant cap layout indicating the fronto-central electrodes (black dots)

- Dipole source analysis was performed using BESA for N1/ P2 dipole fit.
- For statistical analysis, repeated-measured analysis of variance was used to assess the main effects of frequency change (10%, 25%, and 50%), the base frequency (250 and 4000 Hz), and the group (musicians and non-musicians).
- Pearson's correlation coefficient was applied to assess relationships among the behavioral measures and demographic factors with the electrophysiological measures.

RESULTS

Behavioral Frequency Discrimination

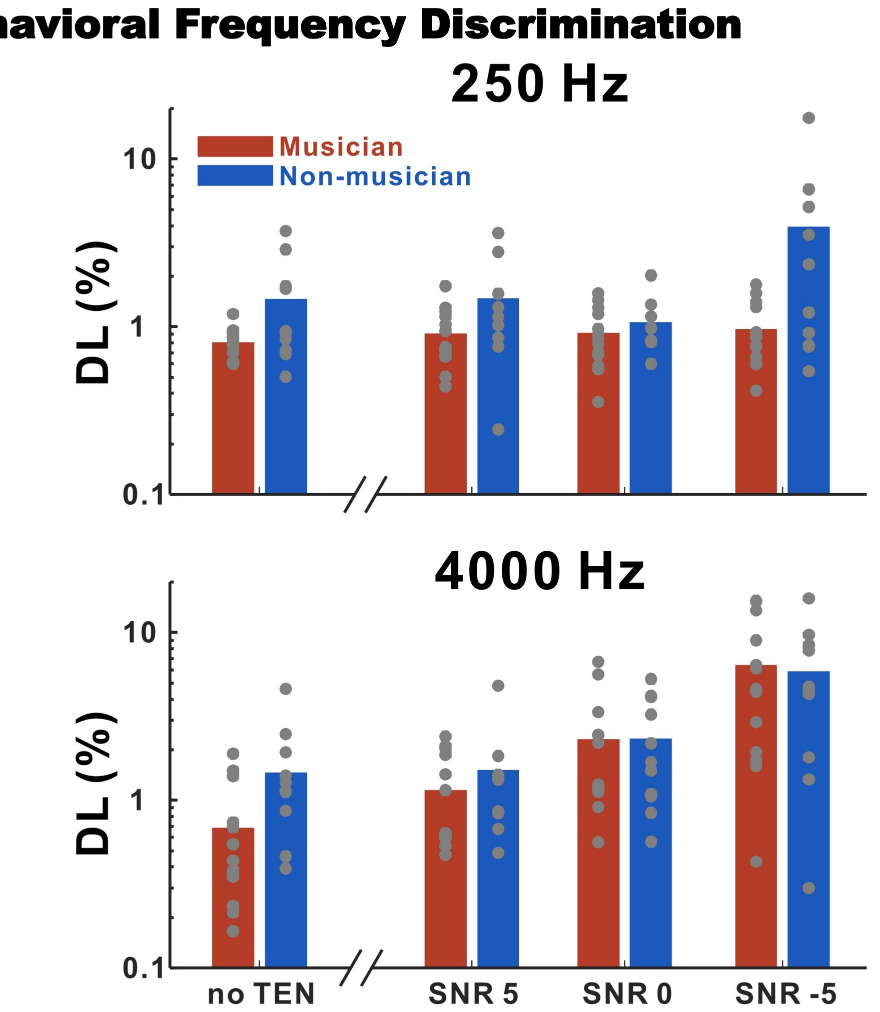


Figure. 3 Mean frequency discrimination thresholds for 250 and 4000 Hz in musicians and non-musicians as a function of listening condition including no threshold-equalizing noise (TEN), SNR +5, 0, and -5 dB. Note that gray dots indicate each subject. Musicians show decreased thresholds compared to non-musicians for both 250 and 4000 Hz in no TEN condition.

Grand mean N1/P2 waveforms as a function of frequency change

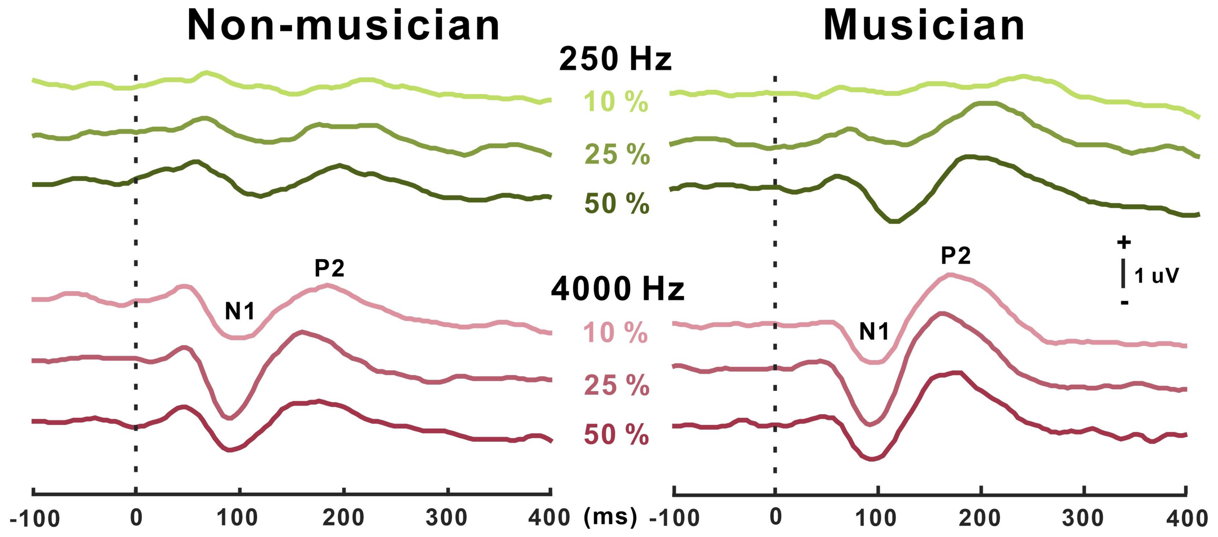


Figure 4. Grand average N1/P2 responses to frequency changes. N1/P2 cortical potentials to frequency change stimuli in non-musicians (left) and musicians (right). Green and red color waveforms represent cortical reponses for 250 and 4000 Hz base frequencies, respectively. The amount of frequency change is indicated as a percentage.

Mean N1/P2 amplitudes as a function of frequency change

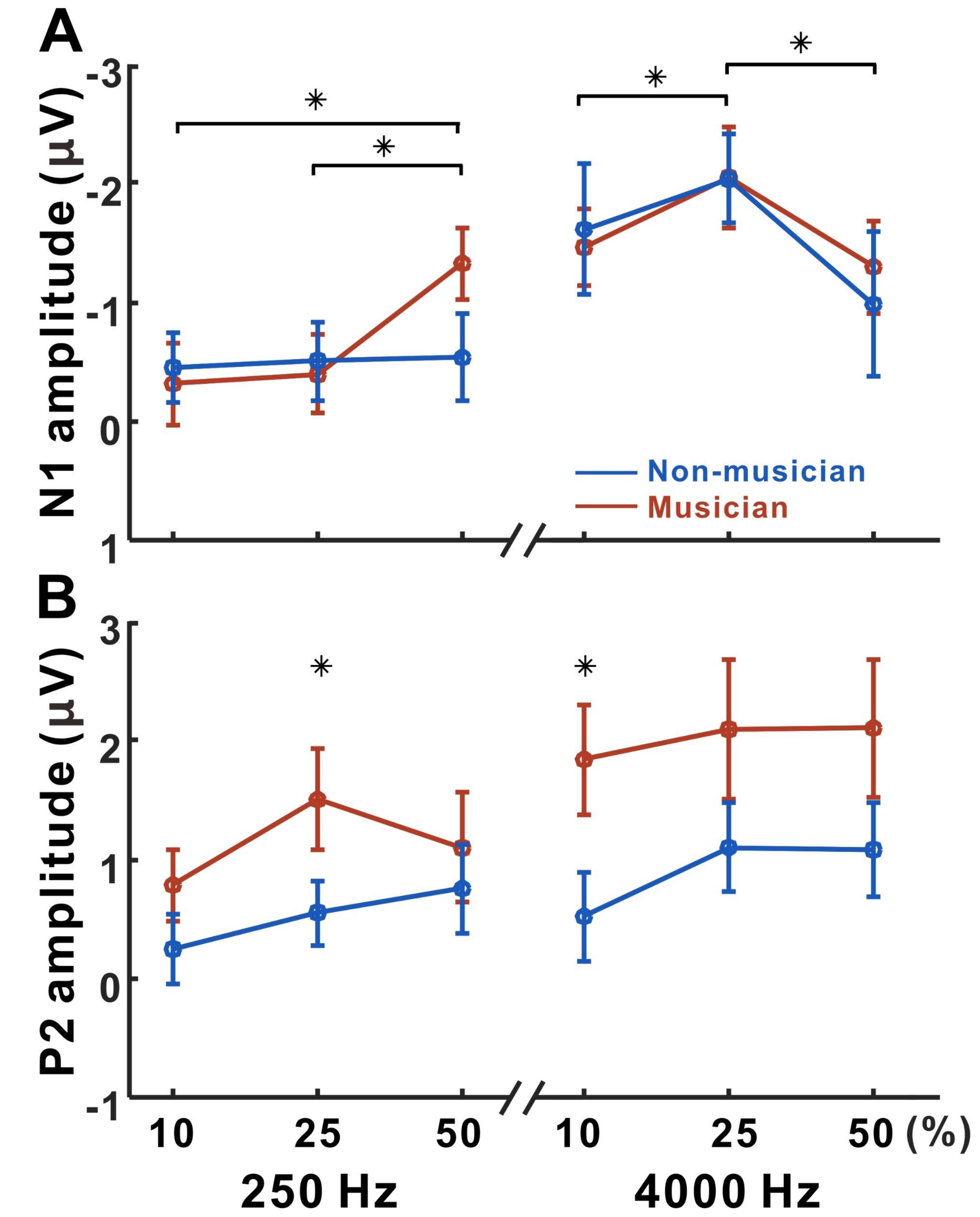


Figure 5. Mean N1 and P2 amplitudes as a function of frequency change. Mean of N1 (A) and P2 (B) amplitudes in musicians and non-musicians are shown. Note that significant differences among listening conditions are revealed for the N1 (250 Hz: 10% vs. 50%, 25 vs. 50%, 4000 Hz: 10% vs 25%, 25% vs. 50%), whereas the differences between musicians and non-musicians are found for the P2 amplitude (250 Hz: 25%, 4000 Hz: 10%). Asterisks (*) indicate significant differences ($p < 0.05$).

Dipole source analysis: Effect of frequency change

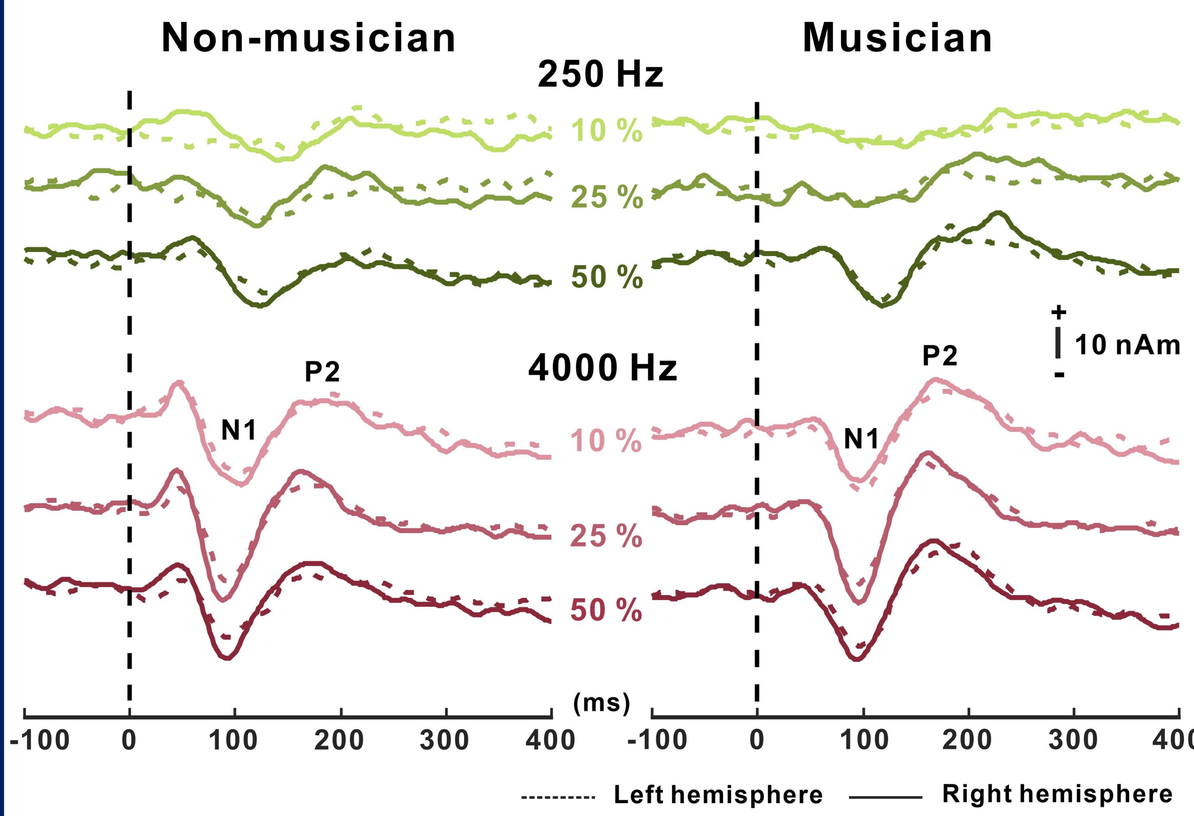


Figure 6. Dipole source waveforms to frequency changes in non-musician and musician groups. N1 dipole source waveforms to frequency change stimuli in non-musicians (left) musicians (right). Green and red color waveforms represent dipole activity for 250 and 4000 Hz base frequencies, respectively. Dashed lines of waveform represent dipole activity in the left hemisphere and solid lines indicate activity in the right hemisphere.

Relationship between N1/P2 amplitudes and behavioral performance/duration of musical training

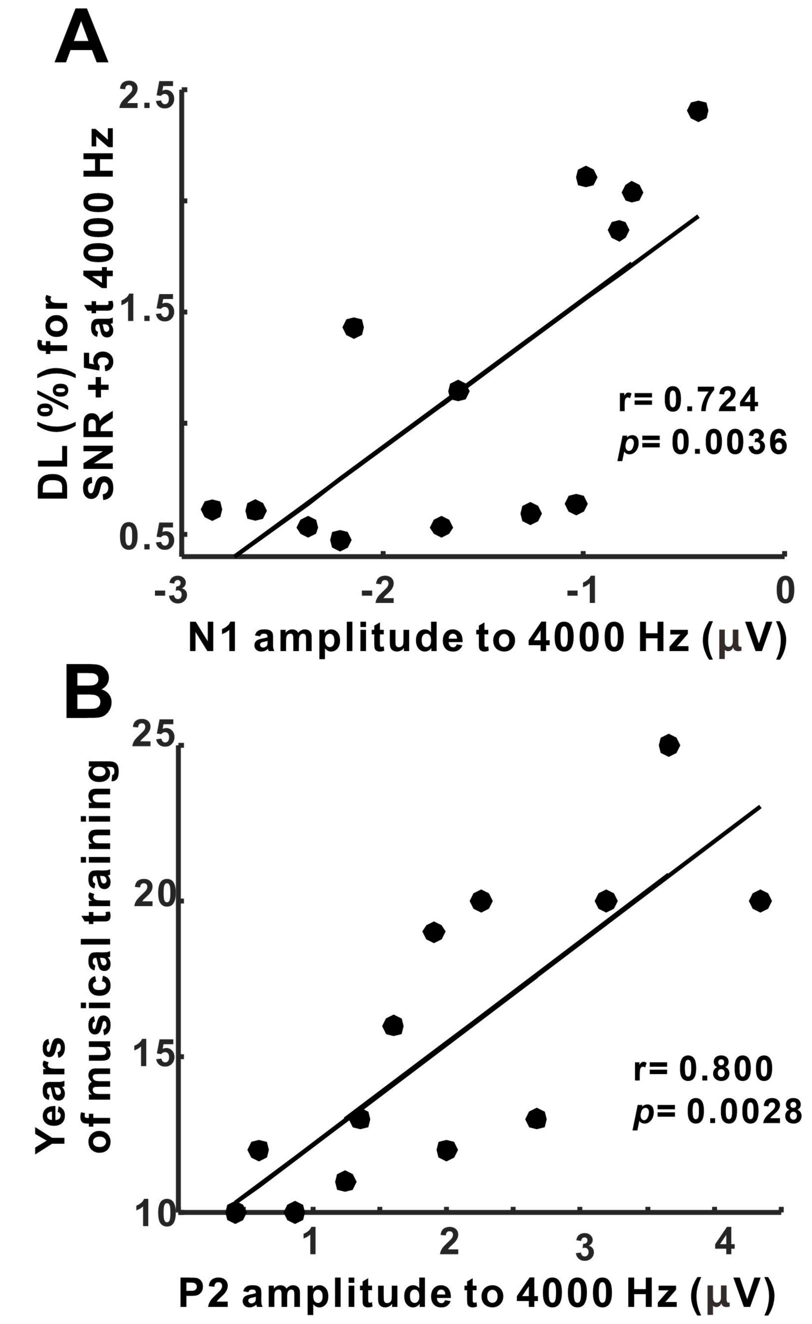


Figure 7. Correlations between behavioral performance/duration of musical training and N1/P2 amplitudes in musicians. (A) N1 amplitudes to 4000 Hz condition are significantly related to frequency discrimination thresholds for SNR +5 at 4000 Hz. (B) A significant relationship between P2 amplitudes to 4000 Hz and the duration of musical training is revealed.

CONCLUSIONS

- In the behavioral frequency discrimination task, the thresholds of the musicians were lower than those of the non-musicians in the no TEN condition, but not the other conditions.
- The effect of frequency change was more apparent for N1, while P2 responses are closely related to musical training.
- An enhanced N1 response to frequency changes is associated with better frequency discrimination.
- P2 responses are positively related to the duration of musician training, indicating training-induced cortical plasticity.
- N1/P2 dipole activity in response to the frequency change stimuli was greater in the right hemisphere.
- Musicians had more robust P2 source activation in both hemispheres, which indicates musical experience may alter the hemispheric lateralization for processing of frequency change more symmetrically.
- Our findings infer that neural plasticity evoked by long-term musical training can alter the cortical representation of a change in frequency.

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