Bachelor’s Degree Final Project

Bachelor’s Degree in Psychology

Neural Encoding of Modulating Frequency and Music Experience

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Abstract

Humans use sounds to communicate with each other. Previous studies have focused on the cognitive advantages of musical experience suggesting that the acquired proficiency can be transferred to the language domain through a more accurate and robust neural processing. However, few studies have evaluated the low-level encoding in the auditory pathway in experienced musicians. Here, we proposed a simple electroencephalography (EEG) experiment which elicits an evoked response potential (the Frequency Following Response or FFR in short) to the frequencies of sound stimuli. Using this design, we did not find differences in the amplitude and signal-to-noise ratio (SNR) of the FFR to the target frequency between 13 musicians and 27 non-musicians. Our results suggest a limited advantage in the neural encoding of auditory information of musical experience in a bilingual context.

Keywords: EEG, FFR, auditory processing, music experience, bilingualism.

Resum

Els humans utilitzem sons per comunicar-nos. Estudis previs s’han centrat en els avantatges cognitius de músics experts, suggerint que l’expertesa adquirida pot ser transferida al domini lingüístic mitjançant un processament neural més afinat i robust. Tanmateix, pocs estudis han avaluat la codificació al nivell baix de la via auditiva en músics experts. Així, hem proposat un experiment senzill d'electroencefalografia (EEG) que provoca una potencial evocat (la Resposta de Seguiment a Freqüència (FFR)) a les freqüències d'estímuls sonors. Emprant aquest disseny, no vam trobar diferències en l'amplitud i la relació senyal-soroll de la FFR a la freqüència diana entre 17 músics i 27 no músics. Els nostres resultats suggereixen un avantatge limitat en la codificació neural d’informació auditiva de l'expertesa musical en un context bilingüe.

Paraules clau: EEG, FFR, processament auditiu, experiència musical, bilingüisme.

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Introduction

We use acoustic information to interact with each other and with our surroundings. Some people are good at mimicking a dialect and others can tune a violin so that the sound tones create a harmony, that is why, different environmental factors come into play.

Among other environmental factors that may shape the observed individual differences in cognitive functions, a great deal of previous studies has focused on the advantages of bilingualism and musical experience. These two abilities are considered to contribute to functional and structural developments on the brain, which also determine one's neural encoding patterns.

In the language domain, bilinguals may have some cognitive advantages relative to monolinguals. These advantages have been observed, for example, in executive control (Krizman, Marian, Shook, Skoe, & Kraus, 2012) but if the task requires more executive control (Moreno, Bialystok, Wodniecka, & Alain, 2010), attention control (Krizman, Skoe, Marian, & Kraus, 2014) and language representation (Sebastian-Gallés, Rodríguez-Fornells, De Diego-Balaguer, & Díaz, 2006). Adults and infants differ in their learning mechanisms (Gervain et al., 2013). Likewise, early and late bilinguals seem to differ in strategy and brain regions in the language processing. They differ substantially in syntactic traits, namely, monolinguals' processing pattern may not correspond to natives' one (Díaz et al., 2016), which suggests the limitations of brain plasticity (Hebb, 2002). Other factors such as identification with a particular language, environments, proficiency also may contribute to the language learning mechanism (Krishnan, Gandour, Ananthakrishnan, Bidelman, & Smalt, 2011).

Music training also requires sensory and high-order processes such as coordination of complex movements. Long-term music engagement may contribute to reorganization of brain processing and its effects persist until adulthood (Bidelman & Alain, 2015). Experienced musicians may develop a specialized sensory system which is sensitive to the particular music intervals when they are compared to those who have less than 3 years of music experience (Lee, Skoe, Kraus, & Ashley, 2009). In addition, some studies suggest a possibility of cross-modal transfer plasticity of music ability. Playing music involves activation and integration of various brain regions, which in turn enhances neural networks of the regions which are responsible for other cognitive functions (Wan & Schlaug, 2010). For example, unlike English, Chinese uses pitch as signal of word meaning. Wong et al., (2007) compared the neural encoding of amateur musicians and no musicians who had no previous exposure to a tonal language when they were exposed to Mandarin Chinese tones. In this study, the musicians showed more robust and faithful encoding of pitch.

Pitch is one of the acoustic information cues common to both language and music domains. In speech, voice pitch bears information concerning emotion, attitude and talker identity (Krishnan, Swaminathan, & Gandour, 2009). In music, pitch variations are a critical component for all musical instruments as their combinations are transformed into melodies (Zatorre, Belin, & Penhune, 2002). As previous studies have shown, both linguistic and musical skills are reflected in the processing patterns at the subcortical and cortical levels. In order to investigate how pitch is processed in the brain, the Frequency Following Response (FFR) is broadly used. It represents a response in the early stage of the auditory information processing to the fundamental frequency (F0) and harmonics of any variety of sounds (Coffey et al., 2019). Its neural generators have been classically located in the brainstem, but recent researches have yielded contributions of cortical structures such as the primary auditory cortex (Bidelman, 2018; Coffey, Herholz, Chepesiuk, Baillet, & Zatorre, 2016). The FFR can be recorded using the electroencephalogram (EEG) applying a band-pass filter as its onset is around 10 ms after the stimulus presentation. The FFR consists of periodic and non-periodic response to sounds and represents a phase-lock activity to sound. The FFR can be observed even if the person is unaware of the target sounds (Skoe & Kraus, 2010) and its periodic portion to the F0 does not seem to be disrupted by background noise (Russo, Nicol, Musacchia, & Kraus, 2004).

Previous researches suggested that tone language speakers, like Mandarin Chinese, are more sensitive to pitch variations of their mother tongue even in a non-speech context (Krishnan et al., 2009). In addition, Mandarin Chinese speaker subjects showed higher pitch-tracking accuracy and pitch strength compared to English speaker subjects when they were exposed to artificially generated Mandarin and Thai words (Krishnan, Gandour, & Bidelman, 2010). The bilingual experience also enhances the FFR response. Skoe et al. (2017) reported that early bilinguals showed robust FFRs to the F0 relative to English monolingual subjects.

With respect to the music experience, musicians may be more sensitive to detect emotions from sound tones (Strait, Kraus, Skoe, & Ashley, 2009) and have an enhanced categorical representation of sounds (Weiss & Bidelman, 2015). Bidelman, Gandour, & Krishnan (2011) found that musicians demonstrated a higher pitch-tracking accuracy and a more robust pitch strength in response to both musical and Chinese tones compared to non-musicians. The authors of this study stated the possibility of cross-domain effects of music experience as experience-dependent plasticity is not only specialized to the relative saliency of acoustic properties but may also contribute to transfer pitch experience to other cognitive domains. In addition, Moreno & Bidelman (2014) suggested that music experience is a factor which enhances the neural transcription of complex sounds in the subcortical domain.

To our knowledge, however, previous studies have not focused on nonlinguistic nor musical tones in a bilingual context. The impact of years of music engagement is even treated as a confound variable in the FFR studies where the targets account for other variables such as bilingualism or tonal language.

Here in Catalunya, two official languages, Catalan and Spanish, are spoken in different settings. Although the proportion of use of each language varies across the population and region, Catalan is a principal language of education from the elementary school to the university. Besides, residents in Catalunya also use Spanish in day-to-day activities.

Objectives

The aim of this study is finding individual differences underlying components of the FFR with respect to music experience. We selected the signal noise-to-ratio (SNR) and amplitude spectrum as indicators of neural encoding. According to years of music experience, two groups were created: musicians and non-musicians.

We hypothesized that the musician group would show more accurate and robust response to the modulating frequency of the sound stimuli used (380 Hz) relative to the non-musician group. Moreover, we expect to have a robust response to the modulating frequency across all trials in both musician and non-musician groups.

Methods

Participants

Data were collected from 40 participants from two independent studies whose experimental codes are namely BB2 and GenVia. Both studies were conducted in 2017 and followed the same procedure. All participants were required to answer the music experience questionnaire, which is a self-reported measure to ask if he or she has played music instruments before. If so, its onset and duration were also provided. According to the duration of music experience, the participants were assigned to the musician or non-musician groups. To this end, we used a threshold of at least 3 years of musical experience (Lee et al., 2009). To conduct the electrophysiological recording, the normality of audition was checked with audiometry test. Participants provided their written informed consent and the study was conducted according to the Declaration of Helsinki and approved by the Bioethics Committee of the University of Barcelona.

Experimental design

Stimuli of 10 different carrier frequencies (ranging between 1537 and 3037Hz) and a modulating frequency of 380Hz were presented binaurally to the participants with a length of 160ms (with 5ms fade-in and fade-out) and an intensity of 85 dB SPL. Stimuli were presented following a roving standard paradigm with 100 trains of 10-14 stimuli (2 trains of each carrier for each train length) with stimulus onset asynchrony (SOA) of 360ms and an intertrain interval of 973ms. The experimental design is summarized in Appendix A.

The experiment lasted approximately 10 minutes. To promote the passive nature of the experiment, participants were instructed to focus on a visual Go/no-Go task unrelated to the auditory stimulation. They were asked to click the button as fast as possible if the number appeared in the screen was the same as the previous one.

EEG recording

We used thirty-six scalp Ag/AgCl electrodes mounted in a nylon cap (Quick-Cap; Compumedics, Charlotte, NC, USA) at the 10-20 standard locations for EEG recording. Four additional electrodes were positioned on the left and right ear lobes (A1 and A2, respectively) and left and right mastoids (M1 and M2, respectively). In addition, two bipolar electrodes were placed above and below the left eye (VEOG) and two horizontal electrodes on the outer canthi of the eyes (HEOG), in order to obtain an electrooculogram (EOG). The ground electrodes located between Fz and FPz and the nose served as reference. The EEG was continuously acquired with Neuroscan 4.4 software and NeuroscanSynAmps RT amplifier (NeuroScan, Compumedics, Charlotte, NC, USA). All impedances were kept below 10kΩ during the whole recording session and data was online bandpass filtered from 0.05 to 3000Hz and digitized with a sampling rate of 20kHz. ABR insert earphones (Etymotic Research, Elk Grove Village, IL, USA) were used to present the stimuli used in the experiment.

Data analysis

EEG recordings were processed by MATLAB R2019 with the EEGLAB package (Delorme & Makeig, 2004). Two features of the FFR were extracted: mean amplitude at the modulating frequency (380Hz) and SNR. For further information of used parameters, see Appendix B.

For the statistical comparisons, the R version 4.0.1 (R Core Team, 2020) and the open source RStudio version 1.3.959 (RStudio Team, 2020) were used (see Appendix C for the used packages). To compare groups, Wilcoxon rank-sum test was used as the condition of normality assumption of the Student t test was not satisfied.

Results

Sample

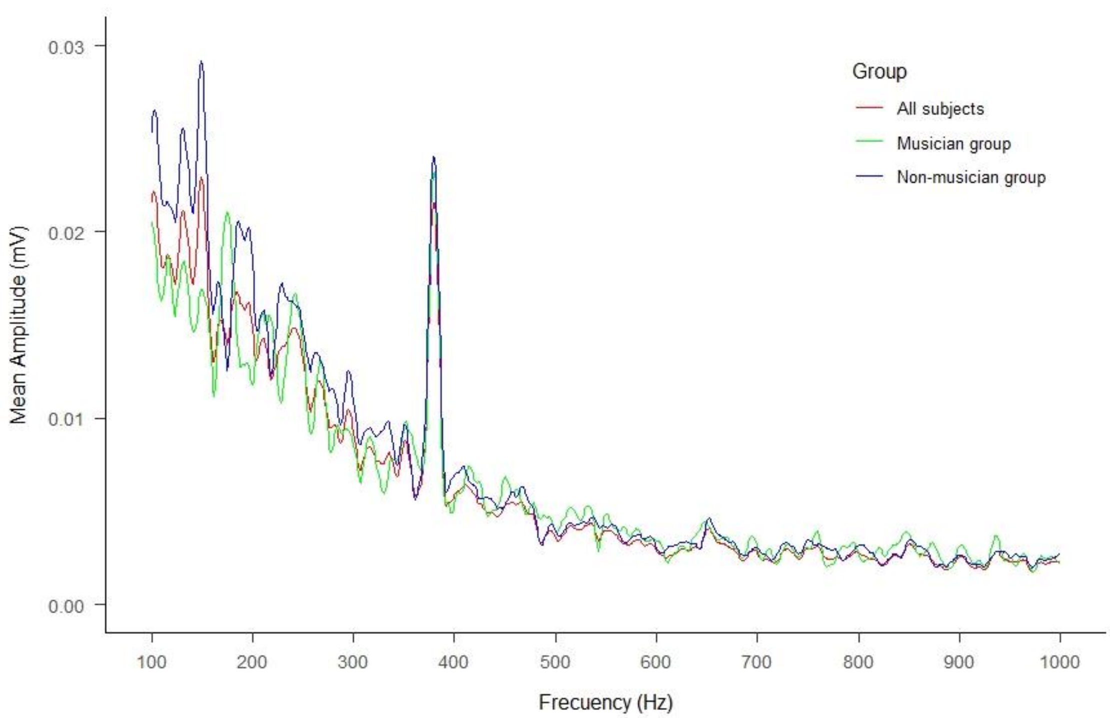
Participants (n = 40; musicians = 13; males = 20; age = 22.32±1.77) in the two groups were matched on the proportion of gender and age (gender: chi-square test, $\chi^2 = 0.013$, df = 1, p = 0.909; age: Wilcoxon rank-sum test, statistic = 182, p = 0.858). Note that 4 participants from the musician group did not report their laterality (both = 1, unknown = 3). Excluding these subjects, laterality was not statistically different between groups (chi-square test, $\chi^2= 1.091$, df = 1, p = 0.296).

FFR data

The experimental procedure successfully elicited an FFR in both groups. As can be seen in Figure 1, participants (both musicians and non-musicians) showed an increase in electric potential at the modulating frequency of the sound stimuli used in the experiment (380Hz).

Figure 1

Frequency Following Response (FFR) at the Modulating Frequency (380Hz)



Mean amplitude and SNR were extracted from the EEG data using two different frequency windows around the modulating frequency of 380Hz (±5 Hz and ±10 Hz). The overall distribution of these FFR features in both groups (musicians and non-musicians) is presented in Figure 2A and 2B.

Figure 2A

Comparison of Mean Amplitude Between Groups

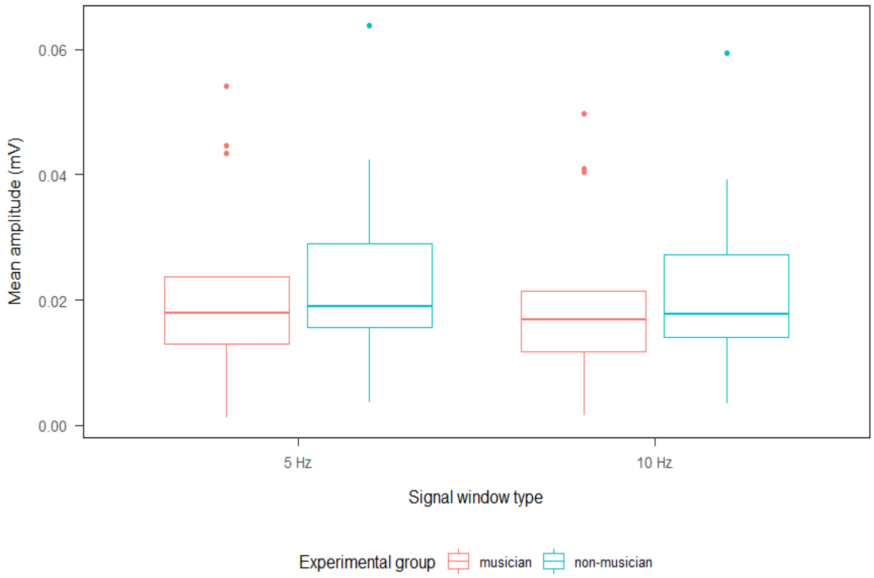
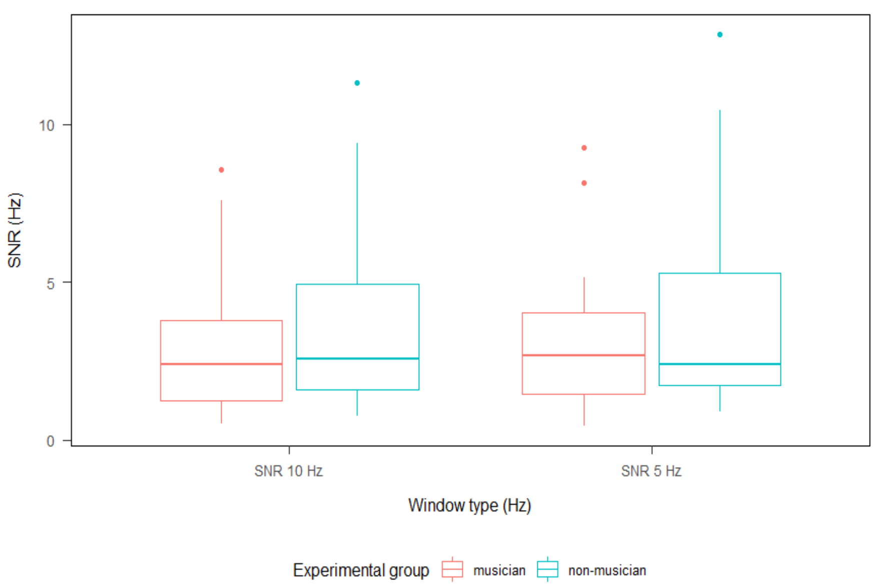


Figure 2B

Comparison of Signal-to-Noise Ratio (SNR) Between Groups



Normality of the data was not guaranteed as indicated by the results of the Shapiro-Wilk tests ($p < 0.05$). The assumption of same variance (homoscedasticity) was satisfied for all comparisons (see Appendix D).

Statistical comparisons between groups

The distribution observed in Figure 3A and 3B revealed that there were not significant differences between musicians and non-musicians ($p > 0.05$ in all conditions). Results from the Wilcoxon rank-sum test did not find statistically significant differences neither for the mean amplitude nor for the SNR at any of the frequency windows considered (Table 1).

Table 1

Descriptive Statistics of the Distributions of Signal-to-Noise Ratio (SNR) and Mean Amplitude

Window	Group	Mean	Median	SD	IQR	P
			SNR (Hz)			
10 Hz	Musician	0.019	0.016	0.014	0.009	0.690
	Non-musician	0.021	0.017	0.012	0.013	
5 Hz	Musician	0.021	0.017	0.016	0.010	0.776
	Non-musician	0.022	0.019	0.013	0.013	
			Mean Amplitude (mV)			
10 Hz	Musician	3.104	2.412	2.550	2.547	0.648
	Non-musician	3.497	2.574	2.744	3.339	
5 Hz	Musician	3.378	2.657	2.722	2.585	0.690
	Non-musician	3.836	2.410	3.061	3.554	

Note. IQR: Interquartile range, p: p-value calculated by Wilcoxon Rank-Sum Test; All values display up to 3 decimals.

Discussion

Contrary to our hypothesis, neither spectral amplitude nor SNR did not reveal differences between the two groups with respect to the response to the modulating frequency. We had anticipated that musicians would show a more robust neural response to the sound stimuli, but our data did not support this assessment.

On one hand, our results may be reflecting the complexity of physical properties of sound and the stimuli that we have used might have been too simple. We have used amplitude modulated tones with a constant modulating frequency instead of more naturalistic sounds, such as speech stimuli or adding background noise, for example. In natural settings, sound characteristics are not constant but more dynamic than flat frequencies. For example, pitch variations are critical components in music and oral communications (Zatorre et al., 2002). This is a possible reason why our results are not in concordance with the previous study (Bidelman et al., 2011). Experienced musicians may be sensitive to some characteristics of sounds, but not to certain frequencies. Likewise, we hypothesize that cross-domain effects of music experience are limited to the sounds with meaningful pitch variations.

Another interpretation of our results could be related to confounding variables. As previous studies have shown (e.g., Skoe et al., 2017), bilinguals present more robust FFR response compared to monolinguals. Moreover, cognitive advantages of bilingual, such as attention and executive control are also reported (Krizman et al., 2012, 2014; Moreno et al., 2010). In the top-down manner, the high order processing may modulate the low-level processing such as the FFR in the early stage of auditory pathway. When it comes to this confounding variable, we should consider that all participants come from the same population in which Spanish and Catalan are used on a day-to-day basis. As previous studies suggested, bilingualism is one of the factors that enhances the FFR response (Skoe et al., 2017). Our results may suggest that this effect of enhancement of the FFR response in a bilingual context might be already present in our sample and may mask or even cancel out the influence of musical experience.

Among potential limitations of our study, our experimental design may have been too short (approximately 10 minutes of EEG recording with 1200 stimuli). Compared to standard FFR experiments that can normally last more than 1 hour, the number of trials used in our experiment is too small to conduct latency analysis, among others, and might have limited the power to detect small differences between groups.

Another potential limitation is that, although our experiment accounts for two different tasks (one auditory and one visual), the result of visual task was not used in the subsequent analyses. This may have prevented from excluding those who answered randomly the visual task. In addition, the used visual task may not be a cognitively high demanding. EEG recordings should be conducted without concentrating intentionally on the target sounds. If the controlled task cannot capture the attention of participants, it could reflect on the EEG recordings.

It is also worth mentioning the characteristics of our sample. In fact, the number of subjects in each group was not equal although the proportions of age and gender were matched. The more subjects there were in both groups, the more probable that catching statistically significant differences in different conditions would be. Moreover, the classification of subjects in two groups according to the music experience questionnaire might also have some limitations in terms of the idiosyncrasy of music activities. For example, not only the onset of music experience but also the setting in which he or she played an instrument differed across the musician group subjects (Lee et al., 2009). Besides, some participants did no longer play any music instrument although they had more than 3 years of music training experience. Other empirical measures such as intensity and frequency of their training could have also been taken into consideration.

Conclusion

Our experimental design allowed to extract the FFR to the modulating frequency in both the musician and non-musician groups. Contrary to our expectations, musicians did not show a more accurate or robust response. Our results support the hypothesis that the enhancement of neural encoding due to the musical experience may be specific to the context and physical property of sounds. Future studies can address these issues that specify the variables of music experience in different settings using a wider variety of sounds.

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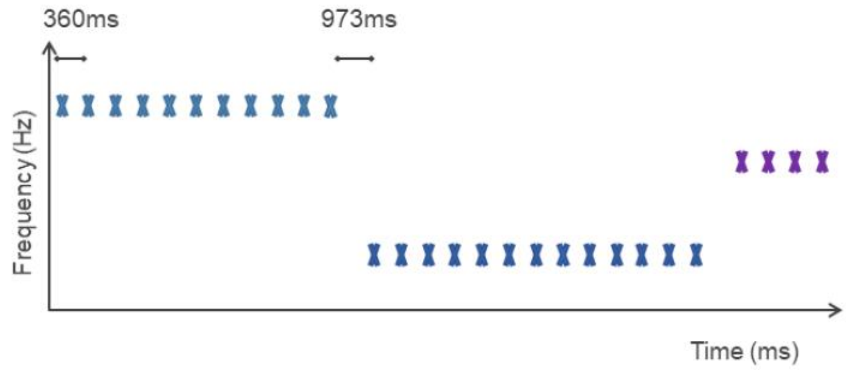
Appendices

Appendix A: Experimental design



Appendix B: EEG processing

To process the data, the electrodes FCz, Cz, CPz, HEOG, VEOG, A1 and A2 were selected. Data was re-referenced to the right earlobe electrode (A2), a bandpass-filter of 75 - 15000 Hz was used and data was epoched by windows of 4 - 20ms for each polarity (P1 and P2). For each subject, grand average was calculated using the CPz. For the mean amplitude spectrum and SNR analyses, the CPz was selected with a time window of 1 - 16 ms adding to it a base line of 4 ms and a sampling rate of 20000 Hz was used. Two SNR window signals, 5 Hz and 10 Hz were tested with a window noise of 20 Hz separated from its signal by 10 Hz.

Appendix C: List of used R packages

papaja (0.1.0.9942), ggpubr (0.3.0), rstatix (0.5.0), forcats (0.5.0), stringr (1.4.0), dplyr (0.8.5), purr (0.3.4), readr (1.3.1), tidyr (1.1.0), tibble (3.0.1), ggplot2 (3.3.0), tidyverse (1.3.0)

Appendix D: Distribution analysis of the different variables

Table 2

Descriptive Statistics of Age

Variable	Mean	Median	Min	Max	SD
Age	22.32	22.00	19.00	27.00	1.77

Table 3

Descriptive Statistics of Gender

Gender	N	Prop
Male	20	50.00
Female	19	47.50
Unknown	1	2.50
Total	40	100.00

Table 4

Descriptive Statistics of Laterality

Laterality	N	Prop
Both	1	2.50
Right	33	82.50
Unknown	3	7.50
Left	3	7.50
Total	40	100.00

Table 5

Descriptive Statistics of Age by Group

Group	N	Mean	Median	Min	Max	SD
Musician	13	22.39	22.00	19.00	27.00	1.90
Non-musician	27	22.30	22.00	19.00	27.00	1.75

Table 6

Wilcoxon Rank-Sum Test by Age

Variable	Group1	Group2	N1	N2	Statistic	P
Age	Musician	Non-musician	13	27	182.00	0.86

Table 7

Descriptive Statistics of Gender by Group

Gender	N	Prop
Musician		
Male	6	46.20
Female	7	53.80
Total	13	100.00
Non-musician		
Male	14	51.90
Female	12	44.40
Unknown	1	3.70
Total	27	100.00

Table 8

Descriptive Statistics of Laterality by Group

Laterality	N	Prop
Musician		
Both	1	7.70
Right	7	53.80
Unknown	3	23.10
Left	2	15.40
Total	13	100.00
Non-musician		
Right	26	96.30
Left	1	3.70
Total	27	100.00

Table 9

Shapiro-Wilk Normality Test by Window and Group

Window	Group	Statistic	P
	SNR		
10 Hz	Musician	0.87	0.05
10 Hz	Non-musician	0.80	0.00
5 Hz	Musician	0.87	0.06
5 Hz	Non-musician	0.79	0.00
	Mean Amplitude		
10 Hz	Musician	0.89	0.08
10 Hz	Non-musician	0.90	0.01
5 Hz	Musician	0.89	0.10
5 Hz	Non-musician	0.90	0.01

Table 10

Levene Test by Groups

Window	DF1	DF2	Statistic	P
		SNR		
10 Hz	1	38	0.01	0.94
5 Hz	1	38	0.04	0.84
		Mean Amplitude		
10 Hz	1	38	0.34	0.56
5 Hz	1	38	0.37	0.55