A STUDY INTO THE NEURAL PROCESSING OF NATURAL MUSIC IN THE BRAINS OF MUSICIANS AND NON-MUSICIANS BY MEANS OF MAGNETOENCEPHALOGRAPHY

Houra Saghafifar
Master's Thesis
Music, Mind and Technology
Department of Music
19 December 2015
University of Jyväskylä

JYVÄSKYLÄN YLIOPISTO

Tiedekunta – Faculty Humanities	Laitos – Department Music Department
Tekijä – Author HOURA SAGHAFIFAR	
Työn nimi – Title A STUDY INTO THE NEURAL PROCESSING OF NATURAL MUSIC IN THE BRAINS OF MUSICIANS AND NON-MUSICIANS BY MEANS OF MAGNETOENCEPHALOGRAPHY	
Oppiaine – Subject Music, Mind & Technology	Työn laji – Level Master’s Thesis
Aika – Month and year November 2015	Sivumäärä – Number of pages 52
Tiivistelmä – Abstract Studying music processing in the brain is a complex task, which involves multidisciplinary skills to achieve the most constructive results. The current experiment investigated MEG brain signals of musicians, music amateurs and non-musicians while they were listening to three different complete music pieces. Brain signals were also recorded while the subjects were resting with their eyes closed and eyes open. The present study aimed to investigate possible differences between neural responses depending on musical expertise and experimental condition (listening vs. resting). These differences were expected in the auditory and motor brain areas. Several ANOVAs were conducted for the data analysis. Results showed that the neural activity for the five experimental conditions was different in several brain areas between musicians, amateurs and non-musicians.	
Asiasanat – Keywords Free-Listening, MEG, MNE, Power Spectrum Density, Musicians, Non-musicians, Neural responses, Alpha, Beta, Low-gamma, Music Processing, Music and Brain	
Säilytyspaikka – Depository	
Muita tietoja – Additional information	

ACKNOWLEDGEMENTS

First of all, I would like to express my biggest gratitude to my supervisors Professor Elvira Brattico, Dr. Tiina Parviainen and Professor Petri Toiviainen, without whom this challenging project would not have been possible to be finalized. It was my great chance to have this opportunity to collaborate with such wonderful circle of expertise to guide me through and give me support to stay motivated with my endeavors.

In addition to my supervisors, I am thankful to Professor Asko Tolvanen, Dr. Marc Thompson, Tuomas Puolivali, Anja Thiede, Mohammad Tabatabaei and Iballa Burunat who gave their valuable time to give me technical support and fruitful advice in order to facilitate the whole process of this study, and also to Jeff Pilgram and Leena Ritokangas for English proof reading.

Big thanks to my mother for always taking care of me and tolerating this distance more than anyone else, also to my deceased father to nurture me and give me the best inheritance, perseverance. Many thanks to my brothers, in-laws and all the distant beloved ones who are always patient listeners to me and are ready to help in all the ways they could.

Special thanks also to my friends in Finland, who made me feel like home here by helping me to overcome the challenges of living and studying in a different society, being as my second family here and making me smile in the moments of disappointments and sadness.

And last but not least, the most important person on my list is my love, Ali Bahrami without whom I could not make this chapter of life complete. Thank you my dearest for always encouraging me to follow my dreams and for all of your supports, sleepless nights, working hard and doing your best to keep me motivated. My lifelong friend: We are the champions!

Jyväskylä, 30.11.2015

Houra Saghafifar

CONTENTS

1 INTRODUCTION

The focus of the current study was in studying the brain processes evoked by natural music listening conditions, and the effect of long-term music training was examined by comparing musicians and non-musicians. In the following section, there is a short review on previous literature related to music, brain and emotions, studies using naturalistic listening conditions, then introducing the MEG (methodology that is used in the present study), and some differences that have been indicated between musicians and non-musicians.

1.1 Literature review

1.1.1 Background

Music plays an important role in every society and culture. It is inseparable from all aspects of our lives like various social and recreational occasions, religious and cultural ceremonies. Many people spend a considerable amount of time daily listening to music or playing a musical instrument. There are hundreds of music networks, mostly free, to listen to music or learn how to play an instrument. What is the reason behind this huge enthusiasm for music?

The most recent studies in the field of music psychology suggest that one reason for the importance of music in human life is that it is able to affect and regulate our moods and emotions, and can be motivational (Zentner, Grandjean & Scherer, 2008; Marin & Bhattacharya, 2009; Salimpoor, Zald, Zatorre, Dagher & McIntosh, 2015; Leow, Rinchon, & Grahn, 2015). A study by Zald and Zatorre (2011) revealed that music is pleasant, rewarding and motivational, based on seven induced positive feelings including wonder, peacefulness and vitality, which consecutively come from the listeners' amazement at the musicians' skills, the relief of tension and energy engagement level in the listeners (Zald & Zatorre, 2011).

The use of music for healing different kinds of illnesses has also been gradually increasing. For instance, one study showed that listening to music enhanced recovery after a stroke (Särkämö & Soto, 2012) and participants who listened to music for two hours a day for a period of two months showed improved visual awareness, enhanced verbal memory and focused attention. Evidence has shown that exposure to music in the laboratory can decrease pain in patients suffering from fibromyalgia (long-term disease with symptoms like exhaustion, sleep disorder, depression and limb numbness) and also help them improve their functional mobility (Garza-Villarreal et al., 2014).

During the last two decades several studies aimed to provide support to the therapeutic effects of listening to music in mental health disorders like depression (Verrusioa et al., 2014; Esfandiari & Mansouri, 2014), anxiety (Argo, Ma & Kayser, 2014; Chen, Hannibal & Gold, 2015), dementia (Särkämö et al., 2012) and autism (Hillier, Kopec, Poto, Tivarus & Q. Beversdorf, 2015).

1.1.2 Music processing in the brain and perceived emotions

Music processing involves disparate regions of the brain, including both the cortical and subcortical structures. While we are doing a musical activity, large networks in the brain, including the frontal lobe, somatosensory and motor-cortex areas, are activated (Zatorre, 2005).

Sound-induced pleasure activates special regions of the brain such as the prefrontal cortex, nucleus accumbens, the cerebellum and amygdala (Blood & Zatorre, 2001; Benovoy, Dagher, Larcher, Salimpoor, & Zatorre, 2010). Furthermore, a correlation has been found between the times of activation in the motor areas and rhythmical scales of music (Popescu, Otsuka & Ioannides, 2004).

What is the reason behind brain exhilaration during musical activities? Different emotions such as happiness, sadness, fear and pleasure are experienced as we listen to music (Koelsch, 2015; Vuilleumier & Trost, 2015); it has been postulated that musical emotions might be culture dependent (Argstatter, 2015) or individual, genre or mood dependent (Fernandez-Sotos, Fernandez-Caballero & Latorre, 2015).

Emotions as a result of listening to music, specifically pleasure, are strongly linked to individual preferences and cultural background. They are also related to a unique musical expectation system in our brains, constructed from the stored sound patterns in the brain during a long time of being exposed to different songs (Salimpoor et al., 2013). Considering the capacity of music to encourage motivation and learning in humans by stimulating dopamine neurotransmission in the mesocorticolimbic reward system, and observing the amount of exposure to music in daily life (Gold, Frank, Bogert & Brattico, 2013), it would be relevant to investigate how long-term exposure to music might modulate brain functions.

Accordingly, by selecting what music to listen to every day, it would be possible to receive a daily dose of endogenous dopamine, stimulate our reward system, maintain reinforcement learning processes in our brain and, consequently, stay positive and motivated.

1.1.3 Naturalistic stimuli: a better paradigm

By using naturalistic complex music stimuli, there would be more tangible and clear outcomes in comparison to a controlled paradigm, especially when music pieces are chosen based on the individuals' preferences. An experimental setting using the naturalistic paradigm, on account of its ecological validity, also would give more freedom to the subjects and minimize stress by avoiding primary tasks that require concentration and artificial button responses. Some previous studies demonstrated that the naturalistic paradigm gave relatively reliable and replicable results (Hasson, Malach & Heeger, 2009; Burunat et al., 2016).

Alluri et al. (2012) were pioneers in using the naturalistic paradigm in music neuroscience, combined with a music information retrieval approach and correlated the timbral, tonal and rhythm features of music with fMRI time series. Their outcomes clearly validated the usage of a naturalistic continuous free-listening condition rather than manipulated artificial stimuli or controlled settings. They obtained more activated areas in the brain in comparison to traditional approaches, including cognitive areas of the cerebellum in response to timbral features, cognitive cortical and subcortical areas along with motor and emotion-related circuits in response to tonality, and finally sensory and default mode network areas in response to rhythmical features.

A subsequent study (Abrams et al., 2013) showed that different brain areas such as the right-hemisphere fronto-parietal attention network and bilateral cortical regions involved in motor planning synchronized while the subjects were listening to natural stimuli compared to music excerpts. In sum, based on these findings, there is enough evidence urging experimenters to design their studies with real-world settings.

1.1.4 Magnetoencphalography (MEG): an accurate neuroimaging tool

To study music processing in the brain, modern neuroimaging methods have been employed increasingly in the past decades. By means of neuroimaging techniques, the involved neural substrates can be tested directly, and this, together with psychophysiological measures, gives a dependable objective method, which limits the subject's conscious intervention (Zald & Zatorre, 2011).

Among all neuroimaging methods, magnetoencephalography is one of the optimal techniques used to study music processing in the brain on account of its high temporal resolution (<1 ms) and adequate spatial resolution (<3 mm) (Hämäläinen, Hari, Ilmoniemi, Knuutila & Lounasmaa, 1993). Additionally, it is a noninvasive method, which measures the magnetic field generated by the signaling of the neurons, with high tech sensors, SQUIDs (Superconductive Quantum Interface Device). Below the (mainly) MEG studies that are the most relevant for the objectives of the current research will be reviewed.

1.1.5 Musicians versus non-musicians

Musicians as creators of emotionally rewarding musical experiences could be the most suitable subjects to be involved in the neuroimaging experiments about music processing in the brain. For instance, musicians showed stronger auditory-cortex responses to musical features than non-musicians, and long-term musical training seemed to be a stimulant for the right planum temporale (Angulo-Perkins et al., 2014). One experiment showed a significant difference in the MEG responses of musicians compared to non-musicians and also in musically complicated pieces rather than simple sounds or tones (Lopez et al., 2003).

In one MEG study, Gestalt and predictive coding theory were tested (Ono, Altmann, Matsuhashi, Mima, & Fukuyama, 2014). The results revealed differences between musicians and non-musicians in how they processed the sound omissions in an array of consecutive tones. In addition, the study showed that musicianship and precision (recognition of the sounds arrangements) interacted with each other to a greater degree in the left Heschl's gyrus and bilateral superior temporal gyrus in musicians than in non-musicians.

Bever and Chiarello (1974) showed that musicians and non-musicians perceived sounds better with opposite ears (musicians with right and non-musicians with left) and left hemisphere was more active in musicians so the study suggested that musicians are more analytical than naïve listeners.

Furthermore, musicians were better in identifying synchronicity of audio/visual stimuli, while in non-synchronic stimuli the left cerebellum was more strongly activated in musicians than in non-musicians, as revealed by MEG responses (Lu, Paraskevopoulos, Herholz, Kuchenbuch & Pantev, 2014). Moreover, in four different experimental settings, Pantev, Paraskevopoulos, Kuchenbuch, Lu and Herholz (2015) showed that musically educated subjects processed the alternation of the multisensory data differently in the auditory cortex.

1.1.6 Neural oscillations in different frequency bands

One of the ways of studying the effects of musical training on the brain (as a long-time specific focused practice) is to investigate neural oscillatory activities while listening to music. The first important step is to carefully select the frequency ranges for the investigation. According to previous literature, the alpha band is related to inhibition (suppression of processing) and the beta band corresponds to sensorimotor (emotional and cognitive) processing (Ray & Cole , 1985; de Lange, Jensen, Bauer & Toni, 2008; Engel & Fries, 2010).

One study conducted by Trainor, Shahin and Roberts (2009) mainly concentrated on the gamma band (30-100 Hz) because of its connection with information/cognitive processing, in order to test the relation between musical training and superior attention and memory skills that were observed earlier by Bhattacharya, Petsche, Feldmann & Rescher (2001). Trainor, Shahin and Roberts (2009) reported stronger gamma band oscillatory activations in adults with formal musical training and also in 5-year-old children after one year of music lessons, compared to non-musically trained subjects, while they were listening to music excerpts.

Bhattacharya et al. (2001) ran one EEG study on mental rotation in the gamma band (30-100 Hz) and their observation of the neural oscillations gave a wider view about cognitive synchronicity and integrity (Bhattacharya, Petsche, Feldmann & Rescher , 2001). In addition, the same study found out lateral differences in the synchronicity level between groups of musicians and non-musicians while listening to music and sounds, and as a result, the left hemisphere, was dominant in musicians, whereas non-musicians showed right-side superiority. There was an assumption in the study that the left hemisphere is mostly linked with analytical thinking.

One MEG study by Krause, Schnitzler and Pollok (2010) showed that there were interactions between the different parts of the brain (primary motor cortex [PMC], thalamus and posterior parietal cortex, [PPC]) at beta and alpha frequency bands. There were three different groups of subjects, drummers, pianists and non-musicians and they were listening to sounds and tapping their right finger simultaneously while listening to a pacing signal. The study suggested that compared to the non-musicians, the drummers showed higher interaction both in PMC-thalamus and PPC-thalamus networks and both in the alpha and beta band, whereas the pianists showed PMC-thalamus interactions just in the beta band.

Accordingly, by reviewing the above studies, focusing on one or more frequency bands is related to the appropriate processes in accordance with the objectives of the research. However, reviewing the frequency bands as widest as possible will give inclusive outcomes.

1.2 Research questions

Although the above-mentioned studies and several others have investigated neural changes induced by musical training, they have typically utilized very controlled experimental paradigms, which limit their generalizability to other experiments and their external validity in real listening situations. To circumvent this, the current experiment has applied the naturalistic paradigm consisting of free listening to real musical pieces. We also included two resting conditions (the situation when subjects were just relaxing with no concentration) both with closed eyes and open eyes.

In addition, previous studies often focused on one certain frequency band (mainly alpha or beta band) and did not report their results corresponding to a wider frequency range; so, based on their relevance for the present study, the following frequency bands were chosen for our analyses: the alpha band (8-12 Hz), the beta band (13-30 Hz) and the low-gamma band (30-45 Hz, before power line frequency: 50 Hz).

Considering which brain areas to focus on, the main interest of this study was auditory processing in the brain, because, first of all, this research is an investigation about listening to music and consecutively auditory areas would be of highest priority to investigate. Secondly, the auditory system of human beings, which is located in the temporal areas of the brain, and more specifically the auditory cortex, is the foremost organ for sound perception (Koelsch, 2012). The auditory cortex is also essential for social interaction and communication, as well as speech perception and recognition (Purves et al., 2012).

Another important brain region in our investigation has been the motor area, in order to observe somatosensory/motor (hereafter somatomotor) processing differences of musicians and non-musicians. The motor area of the brain is located in the vertex and is the main center of all human movements and motor behavior (Beatty, 1995).

Therefore, we focused on the MEG sensors that reflect the activation of the temporal lobe and somatomotor areas.

According to the above-mentioned points, in this study, by means of naturalistic paradigm and MEG recordings, we aimed to find answers to the following research questions:

1) Are there differences in the oscillatory pattern of activations in the brain underlying music listening vs. resting as measured with MEG?

2) Does musical expertise influence the brain oscillations to continuous music listening vs. resting?

3) Are there hemispheric differences in the above effects either in the temporal (auditory) and vertex (somatomotor) areas?

1.3 Hypotheses

The hypotheses of this study are as follows:

1.3.1 Responses in different frequency bands differ for music listening vs. resting

Listening to music can be considered as an activity that needs concentration, and since the chosen music pieces varied considerably, there might be differences between listening to different music pieces, although it is not clear which piece would have the highest response and which one the lowest. Moreover, the expectation is not the same for all frequency bands, because of their different functional significance, and there might be different outcomes under the influence of brain hemispheres, different music stimuli and resting conditions.

The alpha band power is stronger when eyes are closed than when eyes are open, particularly in visual areas. As there might be auditory alpha, which is separate from the visual/posteriorly-evoked alpha, the results might be the opposite. Additionally, alpha band oscillations are associated with resting and inhibition rather than active processing, therefore, it is supposed to decrease when there are more activities in the area. Accordingly, there would be lower alpha power while listening to music than resting. As for the beta and low-gamma bands, which are more linked with processing and activity, there might be different results.

1.3.2 Effect of musical expertise on brain oscillations

The oscillatory activity is expected to differ according to the degree of musical expertise. Here, we investigate to see possible differences between groups in the oscillatory activity either in different frequency bands, in left/right brain hemispheres, in music or resting conditions or for all.

1.3.3 Localization of neural oscillations on brain areas and hemispheres

Based on the objectives of the current study, we observed the oscillatory activity in the channels above the sensory motor (parietal/frontal) cortex, and in the auditory areas (temporal cortex). We assume higher power in the left hemisphere particularly in the temporal areas for musicians. However, there might be dissimilarities for different conditions of the experiments and in different frequency bands for both groups.

2 METHODOLOGY

2.1 About this study

This study is part of two other broader projects, Tunteet[1] and Muscle projects (ethical permission granted by the coordinating committee of the Uusimaa Hospital District), and by applying different signal processing methods aims to investigate differences in the MEG signals to music between musicians and non-musicians.

2.2 Procedure

Data was gathered at the Biomag laboratory of the Helsinki University Hospital with ELEKTA Neuromag MEG device with 306 channels. Before data collection, empty room measurements were done for calculating the noise covariance matrix that is a requirement for the minimum norm estimation (MNE) inverse operator. The EEG was also concurrently acquired with a 32-electrode cap but was not analyzed for the present study. After the MEG session, the participants filled in questionnaires and rated continuously the arousal/valence of the musical pieces with a Nintendo WII device.

The MEG session consisted of 5 experimental blocks. In three of them, the subjects listened to 3 musical pieces (25 min) while keeping their eyes open; in one they were asked to think their own thoughts and rest while keeping their eyes closed (10 min), and in another one they were asked to do the same but keeping their eyes open (10 min). During the data collection and after each music piece, the participants rated their degree of familiarity with the pieces and also their perceived pleasantness from 1 to 5 and almost all subjects were familiar with the pieces (especially Adios Nonino by Piazzolla).

2.3 Participants

Twenty-eight healthy right-handed volunteers (18<age<52) were recruited, fifteen musicians (6F) and thirteen non-musicians (5F). By means of questionnaires, comprehensive

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[1] Tunteet is the Finnish for “ emotions ”.

background information was collected on the subjects’ health condition and background in listening to music and performing music. Musicians started playing their instruments at the age of 10 on average; half of them were pianists and the rest reported playing other instruments such as the drums and the violin. However, most of them reported playing multiple instruments.

The participants’ degree of musicianship was derived from the same detailed questionnaire as above to which a formula was applied based on daily/weekly hours of being engaged in musical activity and the starting age of practicing. Accordingly, the outcome of the formula was a number from 1 to 5 demonstrating the degree of musicianship of each of the subjects. Level 1 belonged to non-musicians, level 2 to amateur musicians and levels 3-5 to musicians who played different genres. Altogether, the participants with the musicianship levels of 1 or 2 were considered as non-musicians and others were identified as musicians.

2.4 Stimuli

During the MEG sessions, the subjects freely listened to three musical pieces of different genres, which were chosen to have variations in melody and harmony in order to obtain a reliable MEG response. Here is a short background of each piece:

- “Adios Nonino” is a well-known and popular tango composition written in 1959 by Astor Piazzolla and in memory of his father’s death. He created a new genre called Nuevo Tango, which merged jazz and classical music into the traditional tango form.

- “Rite of Spring” is a ballet and orchestral work by the Russian composer Igor Stravinsky and the first three dances were selected as a stimulus for this experiment. Stravinsky's musical notations consist of trials in tonality, meter, rhythm, stress and dissonance. This composition is one of the popular classical modern pieces and widely considered to be one of the most influential musical works of the 20th century.

- “Stream of Consciousness” is a progressive metal instrumental song by the band Dream Theater, from the album Train of Thought (2003). The song is very popular among fans and has an alternating characteristic and lots of modulations, which might excite a sense of surprise and unexpectedness in its listeners.

To use simpler terms and avoid confusion, henceforth, we will abbreviate the five experimental blocks as follows: Stream (Stream of consciousness), Piazzolla (Adios Nonino), RoS (Rite of Spring), Rest-Closed (test condition which the subject were resting with closed eyes) and Rest-Open (test condition which the subject were resting with open eyes).

2.5 Data preprocessing

The first and the most challenging part of the data analysis was the preprocessing of the recorded MEG signals, which has mainly been based on the methods described in Hansen et al. (MEG, 2010). Data preprocessing was performed by functions provided by the MNE software (http://martinos.org/mne/stable/index.html). This step overlapped that of another study (Thiede, 2014), concentrating on the inter-subject correlation analysis aspects of the same dataset.

The aim of preprocessing was to remove noise caused by external sources and by subject him/herself (eye blinks or movement), then removing any channels that are noisy/broken from data. This is especially important when looking at continuous data (i.e. when data is not epoched). The preprocessing steps were thoroughly explained as follows:

2.5.1 Finding bad channels in 306 channels manually

MEG has 102 sensors; each consists of two orthogonal planar gradiometers, one magnetometer and also 3 dc-SQUID[2] (Elekta Neuromag oy, 2005). Magnetometer and gradiometer channels (Elekta Neuromag oy, 2005) generally store different types of information during the recordings, i.e. are sensitive to/measure different components of the magnetic fields, B_z (magnetometer), $\frac{\partial Bz}{\partial x}$ and $\frac{\partial Bz}{\partial y}$ (planar gradiometers).

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[2] Superconductive Quantum Interface Device

The following figures extracted from the Elekta technical user manual (p. 14 &15), illustrate respectively the layout of 102 MEG sensors in a form of a helmet[3] and also the structure of each sensor:

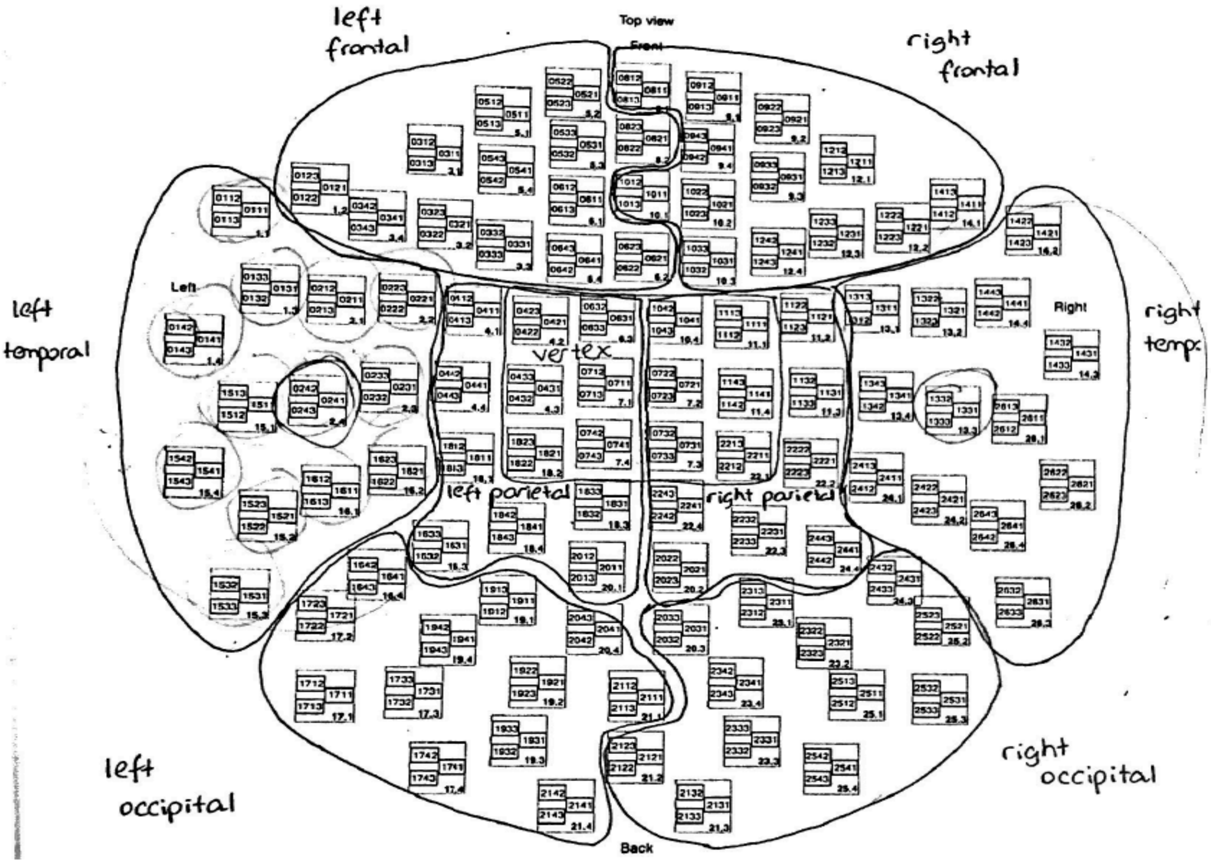

Figure 1. MEG sensor layout

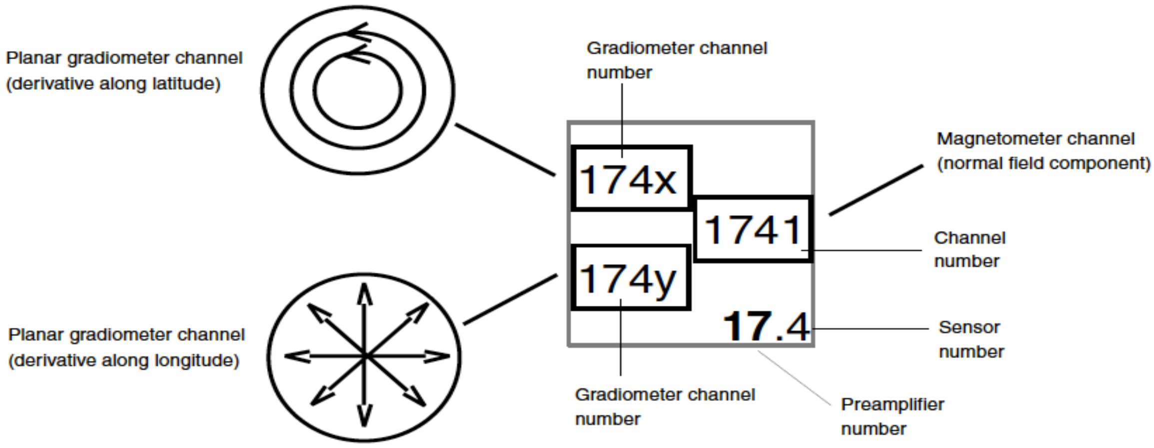

Figure 2. Structure of a MEG sensor (x and y could be 2 or 3 based on the channel's location.)

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[3] The categorization in the figure is corresponding to the different regions of the brain and their lateralization.

The information related to figure 1 in a more clear way is shown in table 1:

TABLE 1. Corresponding MEG sensors with brain regions

Brain region	Number of channels	Sensors' codes[4]
Right Frontal	39	5.2, 5.1, 5.3, 8.2, 3.1, 5.4, 6.1, 1.2, 3.4, 3.2, 3.3, 6.4 & 6.2
Left Frontal	39	8.1, 9.1, 9.2, 9.4, 9.3, 12.1, 10.1, 10.2, 10.3, 12.3, 12.4, 12.2 & 14.1
Right Vertex	18	10.4, 11.1,7.2, 11.4, 7.3 & 22.1
Left Vertex	18	4.2, 6.3, 4.3, 7.1, 18.2 & 7.4
Right Parietal	21	11.2, 11.3, 22.2, 22.4, 22.3, 20.2 & 24.4
Left Parietal	21	4.1, 4.4, 18.1, 16.3, 18.4, 18.3 & 20.1
Right Temporal	39	14.2, 13.1, 13.2, 14.4, 14.3, 13.4, 13.3, 26.1, 26.2, 24.1, 24.2, 26.4 & 26.3
Left Temporal	39	1.1, 1.4, 1.3, 2.1, 2.2, 15.1, 2.4, 2.3, 15.4, 15.2, 16.1, 16.2 &15.3
Right Occipital	36	20.3, 23.1, 24.3, 23.4, 23.2, 25.2, 25.1, 25.3, 21.2, 23.3, 21.3 & 25.4
Left Occipital	36	16.4, 17.2, 19.1, 19.4, 20.4, 17.1, 17.3, 19.2, 21.1, 17.4, 19.3 & 21.4

We started the data preprocessing by visual inspection of those above-mentioned 306 MEG channels. Since the Maxfilter software could not find all bad channels automatically, we had to identify them by observing all channels separately for each of the subjects, either via the graphical interface software "Graph software" (part of the Elekta Software package) or the "mne_browse_raw", part of the MNE software. All channels were scrutinized thoroughly in the whole signals' time series for abnormal behavior such as noise, distortion or artifact. The next step was to review all details about the bad channels and put the ensured ones on a final list to mark them as bad. After having all bad channels assigned, we ran Maxfilter to remove noise from data.

2.5.2 Applying SSS by Maxfilter to remove external noise

Signal Space Separation (SSS) was applied through Maxfilter software (part of Elekta Neuromag) in order to remove noise caused by external sources from data.

2.5.3 Applying PCA and SSP for removing artifacts

The last part of preprocessing aimed to do corrections for the cardiac rhythm (ECG), eye movements and eye blink artifacts. The Principle Component Analysis (PCA) and Signal Space Projection (SSP) were applied to the data in order to remove artifacts.

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[4] A number at the right end of the squares surrounds each cluster of three neighbouring channels.

2.6 Data analysis

2.6.1 Choosing specific sensors to investigate

The analysis of cleaned MEG data started based on using FFT[5] for estimating power spectral density (Welch, 1967) via MNE Python and Matlab codes. The first step in the data analysis was to extract the numerical data from ".fif" files and then, decide which sensors to choose to analyze from the pool of the 102 MEG sensors (see figure 1).

For visualization, we calculated the power spectrum density amplitudes (2-100 Hz band-pass filter & nfft6=2048) in the whole brain topography for each subject. Subsequently, we obtained overlaid power spectrum density curves and amplitudes of the 306 channels of the five different conditions of the experiment. Figure 3 shows an example of a topography map:

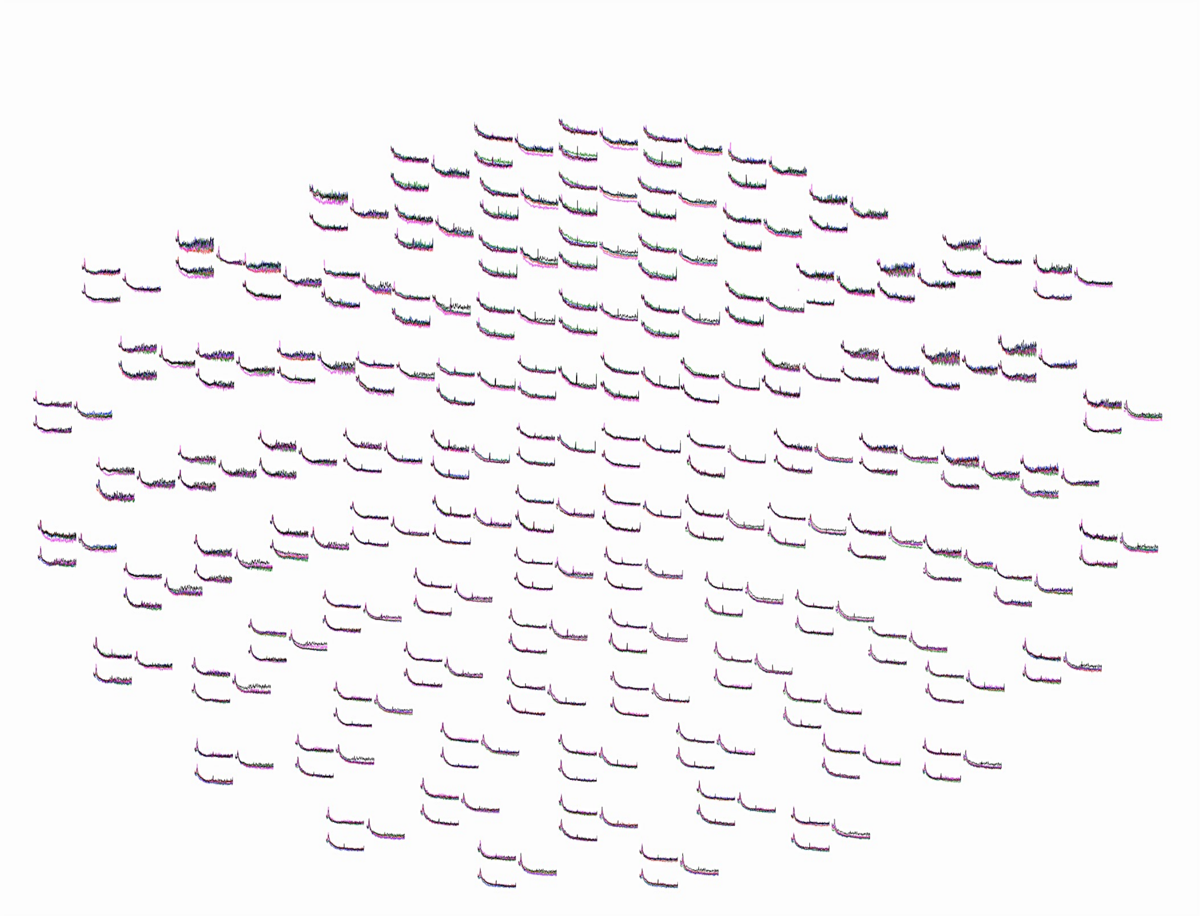

Figure 3. Whole brain topography of 5 conditions overlaid for a musician (Male/Pianist)

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[5] Fast Fourier Transform

[6] Length of discrete Fourier transform, preferably power of two by using 2x window length.

Different colors were used to show different conditions of the experiment (blue: Stream, red: Piazzolla, green: RoS, magneta: Rest-Closed and black: Rest-Open). Figure 4 illustrates an enlarged example of these curves, from 2 to 100 Hz, for one auditory channel (MEG 0242) located in the left temporal of a randomly selected musician subject. The y-axis represents the amplitudes of the power spectrum density and the x-axis stands for their corresponding frequencies:

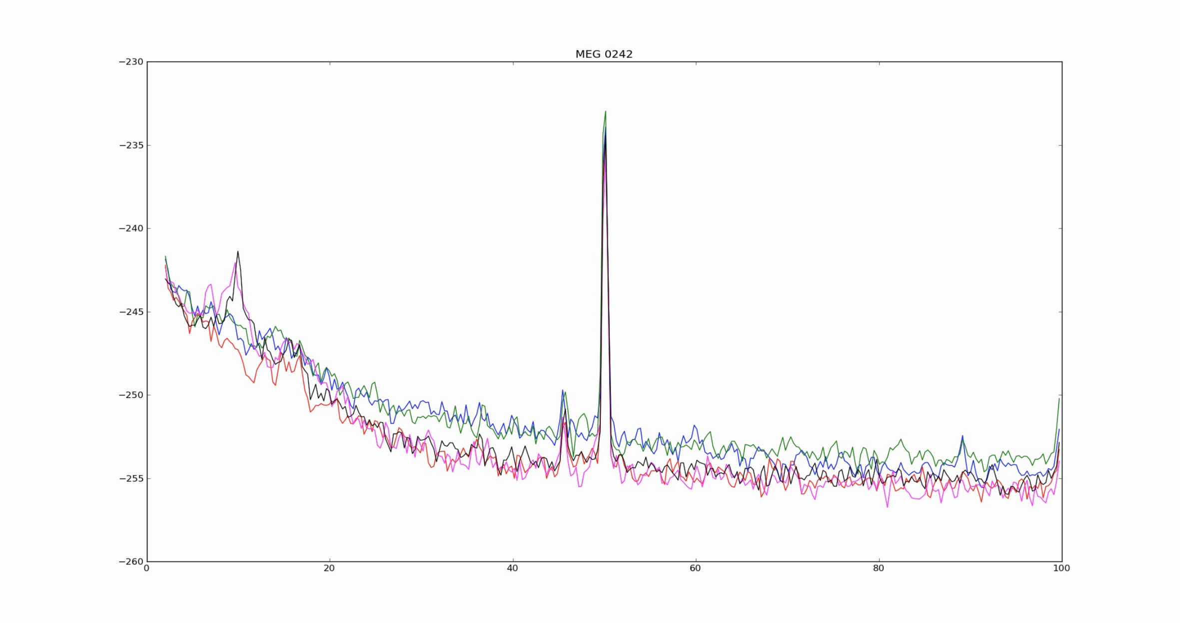

Figure 4. Power spectral density graph for a musician (Male/Pianist)

The outcome of the topographical maps was taken as the calculated power spectrum density for all channels and also separately for each subject. In all, we had 140 matrices (13 for non-musicians and 15 for musicians multiplied by 5 conditions of the experiment), with a size of 306*336. In each matrix, rows and columns represented the channel number and amplitudes of power spectrum density in a certain frequency, respectively.

For collecting measures for statistical analysis we selected specific sensors of interest from somatomotor (vertex) areas and from auditory (temporal) areas. The number of sensors in each area was 26 sensors (78 channels) in the left and right temporal areas and 12 sensors (36 channels) in the left and right vertex. Concerning the selection of the individual sensors of interest, we used gradiometer channels as they show the maximum signal directly above the activated brain area. Then, we averaged the power spectrum density amplitudes over subjects within each group for all gradiometer channels in the temporal and vertex areas and in the whole frequency range (2-100 Hz).

Subsequently, we overlaid the curves of all gradiometer sensors in both the temporal and vertex areas. We did the same for each cerebral hemisphere and also for each stimulus separately. The purpose was to illustrate the average group signals' behavior and identify the signal with the highest amplitude. Figure 5 and 6 illustrate the steps explained above:

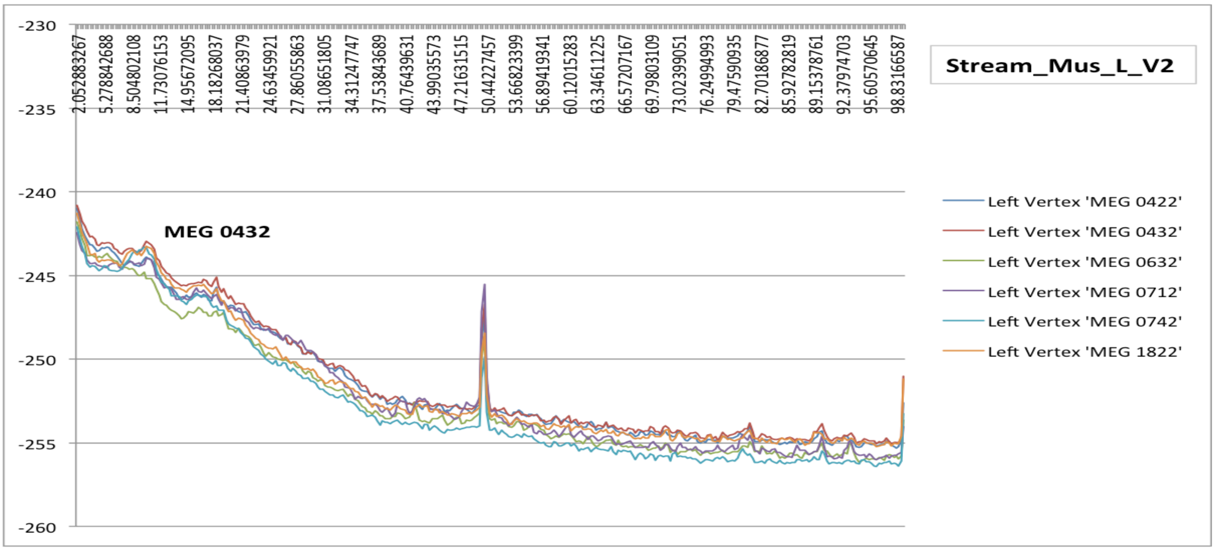

Figure 5. Left Vertex gradiometer sensors / average curves / Musicians

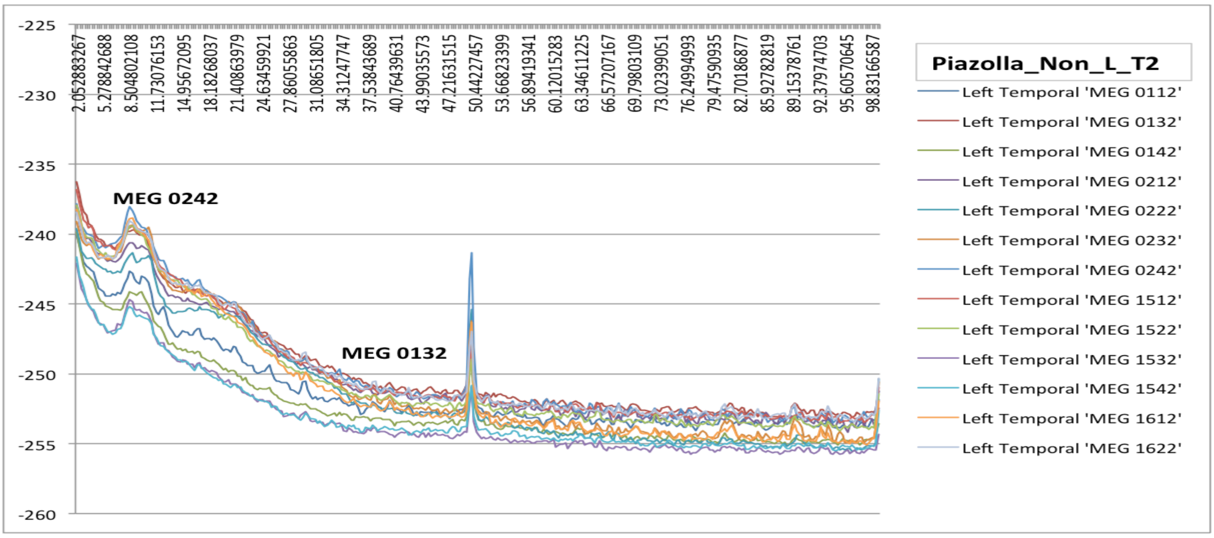

Figure 6. Left Temporal gradiometer sensors / average curves / Non-musicians

For all channels within these selected areas (temporal and vertex) we measured the highest amplitudes in different frequency ranges (2-8 Hz, 8-12 Hz, 12-30 Hz and 30-50 Hz) by computing the maximum value of that specific frequency range. Table 2 is an example of selected channels with the highest amplitude in each frequency band:

TABLE 2. Sensors with the maximum value for 2-8 Hz frequency band

Brain area / Hemisphere	*Group*	*Highest Amp Channel / Condition*				
		Stream	*Piazzolla*	*RoS*	*Rest-Closed*	*Rest-Open*
Temporal / Left	Musician	**MEG 0132**	**MEG 0132**	**MEG 0132**	**MEG 0132**	**MEG 0132**
	Non-Musician	MEG 0132	MEG 0132	MEG 0132	MEG 1512	MEG 0132
Temporal / Right	Musician	**MEG 1442**	**MEG 1442**	**MEG 1442**	**MEG 1442**	**MEG 1442**
	Non-Musician	MEG 1442	MEG 2612	MEG 1442	MEG 1442	MEG 1442
Vertex / Left	Musician	MEG 0432	MEG 0432	MEG 0432	MEG 0432	MEG 0422
	Non-Musician	**MEG 0432**	**MEG 0432**	**MEG 0432**	**MEG 0432**	**MEG 0432**
Vertex / Right	Musician	MEG 1142	MEG 1142	MEG 1142	MEG 1042	MEG 1142
	Non-Musician	MEG 1142	MEG 1142	MEG 1112	MEG 1142	MEG 0732

In table 2, bold numbers show channels that are similar in all conditions and highlighted channels represent those matched in both hemispheres. After scrutinizing all the tables in the four different frequency bands, we chose those channels with a maximum in all or most of the conditions for both of the groups and also for the categories of different frequency bands in this grand average data.

For somatosensory/motor (vertex) areas in the left and right hemispheres, it was straightforward to pick one channel in both groups and for all frequency bands. As for the auditory (temporal) areas in the left and right hemispheres, the maximum was detected in different channels for different frequency bands, so we chose two channels.

To sum up, we finalized this process with six gradiometer channel pairs in each hemisphere, for which the final analysis was conducted. The selected channels were as follows: MEG 0132/MEG 1442 (left/right temporal), MEG 0242/MEG 1332 (left/right temporal) and MEG 0432/MEG 1142 (left/right vertex). Accordingly, the corresponding sensors of these gradiometer channels, 1.3/14.4, 2.4/13.3 and 4.3/11.4 (see table 1 for the sensor codes and locations), were chosen for the statistical analyses. Regarding to the locations of these sensors in the sensor layout (see figure 1), we will call these sensors hereafter, anterior-auditory, core-auditory and somatomotor sensors, respectively.

2.6.2 Statistical analysis

Next, we calculated the RMS[7] (Root Mean Square) of the gradiometer channel pairs of each sensor to achieve a general power value in the whole frequency range (2-100 Hz). Therefore, our final values were calculated with the following equation, where Amp_2 is amplitude of the gradiometer channel with ending 2, Amp_3 is the amplitude of the gradiometer channel with endings 3, and Amp_{rms} is the RMS of both channels:

$$Amp_{rms} = \sqrt{\frac{(Amp_2)^2 + (Amp_3)^2}{2}}$$

Then, we calculated the final power values by getting the average of the RMS amplitudes for each subject and frequency band and sensor separately. We used repeated measures MANOVAs to test the effect of musical expertise on oscillatory power in three different frequency bands and in three different locations in the two hemispheres.

We conducted nine MANOVAs, one for each sensor pair (anterior-auditory, core-auditory and somatomotor) and separately for each frequency band. We had a between subject factors with two levels named Group (musicians vs. non musicians).

The first factor, named Condition, represents five conditions of the experiment, Stream, Piazzolla, RoS, Rest-Closed and Rest-Open, respectively. The second factor, named Hemisphere, represents the left and right hemispheres, respectively. So as a whole we had ten dependent variables. Table 3 illustrates all the information related to the variables and number of subjects in each group:

---

[7] $x_{rms} = \sqrt{\frac{(x_1+x_2+\cdots+x_n}{n}}$

TABLE 3. Variable and groups information

Hemisphere	*Condition number*	*Variable*	*Group*	*N*
Left	1	Stream.1	1	15
			2	13
			Total	28
	2	Piazzolla.1	1	15
			2	13
			Total	28
	3	RoS.1	1	15
			2	13
			Total	28
	4	Rest-Closed.1	1	15
			2	13
			Total	28
	5	Rest-Open.1	1	15
			2	13
			Total	28
Right	1	Stream.2	1	15
			2	13
			Total	28
	2	Piazzolla.2	1	15
			2	13
			Total	28
	3	RoS.2	1	15
			2	13
			Total	28
	4	Rest-Closed.2	1	15
			2	13
			Total	28
	5	Rest-Open.2	1	15
			2	13
			Total	28

For significant interactions between factors and better understanding of the results, we ran additional ANOVAs separately for music conditions and resting conditions. To test the differences between conditions and also for interaction effect of the hemispheres on conditions, we used simple contrast ANOVA. In addition to check the effect of location of the sensors in the MEG sensor layout for the two sensors in auditory areas in each hemisphere, we ran paired t-tests for anterior-auditory and core-auditory sensors.

In our analyses, we checked main effects of each factor, i.e. possible effect of hemisphere, condition and group in the data. We also looked at possible interactions of the factors to each other. Especially we were interested to see whether oscillations in musicians and non-musicians would overall differ from each other (main effect of group) or only in one hemisphere (interaction Group*Hemisphere) or differently for different conditions (interaction of group by condition).

In case of significant interactions, we ran another ANOVA to see the sources of the interaction. For instance, to check the interaction effect of condition and hemisphere, we ran separate ANOVAs with just one of the hemispheres.

The results tables can be seen in the appendices and the outcomes of the MANOVAs will be explained thoroughly in the results section.

3 RESULTS

The results of the within-subjects MANOVAs addressed our research questions about the differences between groups (musicians vs. non musicians), different conditions of the experiment and also possible hemispherical effects. Therefore, we checked all the possible interactions including the effect of hemisphere, the effect of the conditions of the experiment, the interaction effects of hemisphere and group, condition and group, hemisphere and condition, and finally, interaction effect of hemisphere, conditions and group altogether. Summary of the results tables can be seen in the appendices. Each table contains the results of all sensor pairs of the study and separately for each frequency band. Next, we report the results for each frequency band respectively, in accordance with the research questions of the current study.

3.1 Alpha band (8-12 Hz) MANOVAs results

3.1.1 Temporal area

In the temporal area, there was a highly significant difference between conditions both in the core-auditory ($P<0.001$) and anterior-auditory sensors ($P<0.001$). There was no general group difference in the alpha band in any of the channels/areas. All values can be seen in the table of results, appendix 1, table 1.

For separate test of music conditions, the alpha power in both core-auditory and the anterior-auditory sensors showed a significant difference for Condition ($P<0.01$, for both sensors). For the core-auditory sensor there were also significant interactions for Condition by Group ($P<0.05$) and Condition by Hemisphere ($P<0.05$). All values can be seen in the table of results, appendix 2, table 1.

As for separate test of resting conditions, Condition significantly differed ($P_{\text{Anterior}}<0.001$ & $P_{\text{Core}}<0.001$). There was also a significant effect of Hemisphere ($P_{\text{Anterior}}<0.05$ & $P_{\text{Core}}<0.05$). All values can be seen in the table of results, appendix 3, table 1. Figure 7 illustrates the difference between groups separately for each hemisphere in the temporal area:

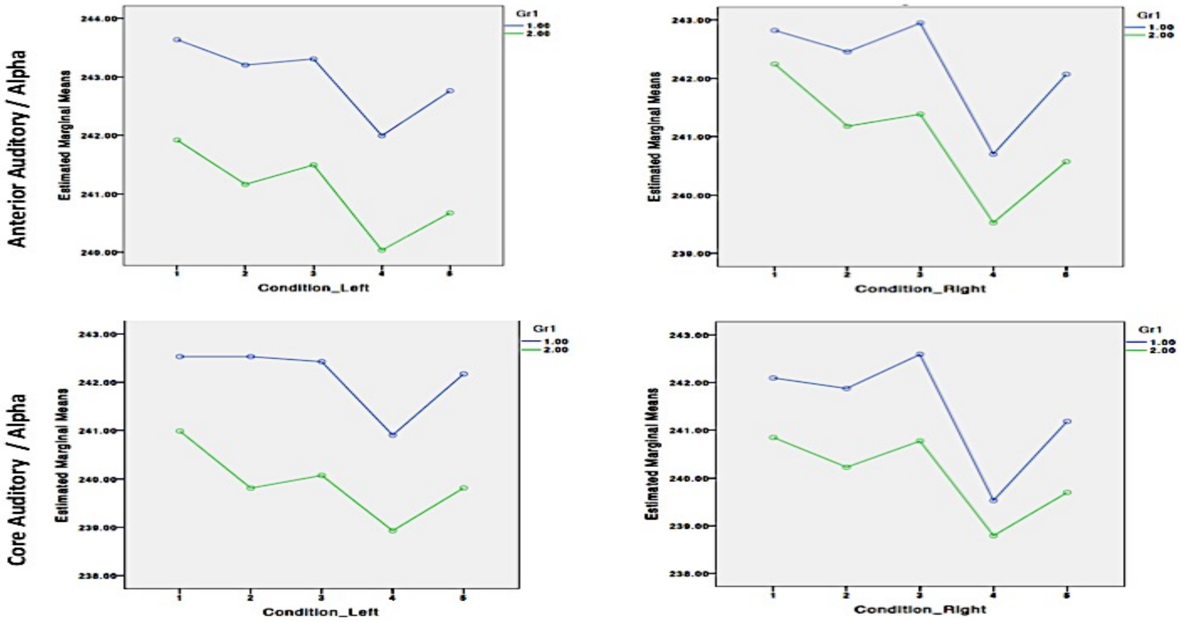

Figure 7. Alpha band / Temporal area / Conditions in different hemisphere

In figure 7, each hemisphere is shown in separate columns and each sensor in different rows. In each of the subplots, the x-axis stands for the conditions of the experiment and number 1 to 5 represent each condition with this order: Stream: 1, Piazzolla: 2, RoS: 3, Rest-Closed: 4 and Rest-Open: 5. The y-axis shows the amplitude of the selected sensors in different conditions. The groups are shown in different colors, blue for musicians (group 1) and green for non-musicians (group 2).

Based on the visual inspection of the figure above, in general, musicians showed higher alpha values than non-musicians. For music conditions, Piazzolla (2) showed the lowest alpha values in both groups except for the core-auditory sensor in the left hemisphere for musicians' group.

The general trend in the left hemisphere is that the first condition, Stream (1), seemed to have the highest power and Piazzolla (2) the lowest power, except for the core-auditory in musicians. In the right hemisphere, still piazzolla had the lowest power in both sensors and for both groups and Stream (1) and RoS (3) seemed in parallel, except for anterior-auditory in non-musicians. As for resting conditions, Rest-Closed (4) showed lower power than Rest-Open (5) for both sensors, both hemispheres and both groups.

3.1.2 Paired t-test for comparing amplitudes of auditory sensors

To check the effect of the sensors' locations in one oscillatory power within temporal area, we ran paired t-tests (two tailed, 95% confidence interval) for the selected sensors from the temporal area, anterior-auditory and core-auditory sensors. We compared all the Condition*Hemisphere pairs for power values of these two sensors for both groups and in all, we had ten pairs to compare. Results showed that in the alpha band, the differences between all pairs were significant, except for one pair, RoS in the right hemisphere. All values can be seen in the table of results, appendix 4, table 1.

3.1.3 Vertex area

In the vertex area, there was a significant difference between hemispheres (P<0.001) and between conditions (P<0.05). The effect of Condition was also tested separately for music conditions (Stream, Piazzolla and RoS) and rest conditions (eyes-closed and eyes-open) and it was significant in both tests. There was no general group difference here. All values can be seen in the table of results, appendix 1, table 1.

For separate test of music conditions, again the alpha power in somatomotor sensor showed a significant difference for Condition (P<0.01) and also Hemisphere (P<0.01). All values can be seen in the table of results, appendix 2, table 1.

As for separate test of resting conditions, just Condition (P<0.001) and Hemisphere (P<0.01) significantly differed. All values can be seen in the table of results, appendix 3, table 1. Figure 8 illustrates the difference between groups separately for each hemisphere in the vertex area:

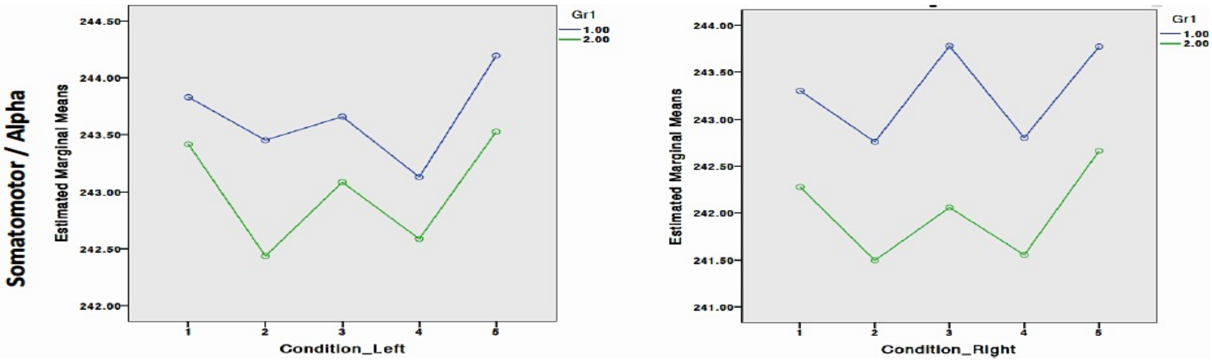

Figure 8. Alpha band / Vertex area / Conditions in different hemisphere

The description of the elements in figure 8 is similar to figure 7 (See 3.1.1, paragraph 4). According to figure 8, in general, musicians (blue color) showed stronger alpha values than non-musicians (green color) in both hemispheres.

For the three music conditions, Piazzolla (2) showed the lowest alpha values in both hemispheres for both groups and Stream (1) alpha values were higher in the left hemisphere for musicians and in the right hemisphere for non-musicians whereas RoS (3) alpha value was higher in the right hemisphere for musicians.

In the resting conditions, similar to the temporal area, Rest-Open (5) showed stronger alpha values than Rest-Closed (4) for both sensors, both hemispheres and both groups.

3.2 Beta band (13-30 Hz) MANOVAs results

3.2.1 Temporal area

Similar to alpha, there were no general group differences in the beta band activity. There was a significant difference for Condition both in the core-auditory and anterior-auditory sensors ($P<0.05$, for both sensors). The interaction effect of Group*Hemisphere was also significant ($P<0.05$). All values can be seen in the table of results, appendix 1, table 2.

For separate test of music conditions, there was no significant result. All values can be seen in the table of results, appendix 2, table 2.

For separate test of resting conditions, there was a significant Group*Hemisphere interaction in the core-auditory sensor ($P<0.05$), validating the hemispherical difference in resting conditions between musicians and non-musicians. All values can be seen in the table of results, appendix 3, table 2.

Figure 9 illustrates the difference between groups separately for each hemisphere in the temporal area:

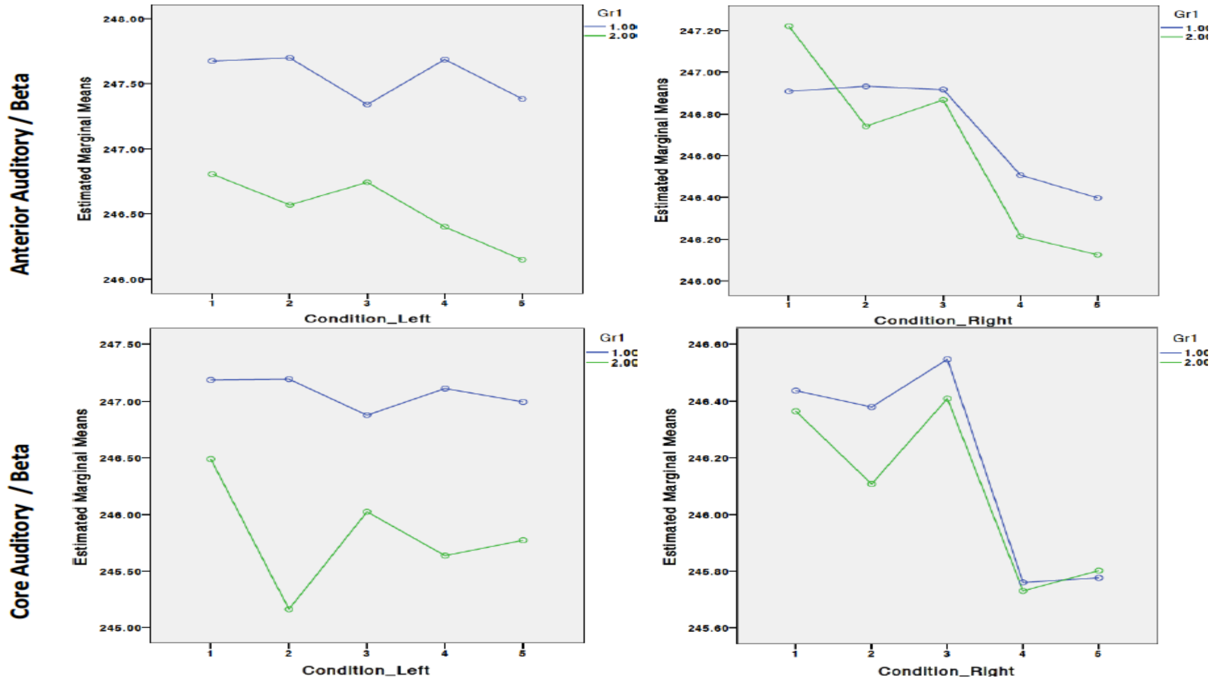

Figure 9. Beta band / Temporal area / Conditions in different hemisphere

The description of the elements in figure 9 is similar to figure 7 (See 3.1.1, paragraph 4). As can be seen in figure 9, there is no common interpretation between different hemispheres.

For music conditions, musicians (blue) showed in general, higher power than non-musicians with Piazzolla (2) at the highest power for musicians and contrarily the lowest for non-musicians in both sensors, both hemispheres and both groups. However, there are some exceptions. In the right anterior-auditory Stream (1) in non-musicians seemed to have the highest power and all music conditions showed quite similar values for musicians. Additionally, in the right core-auditory, Piazzolla had the lowest value for musicians.

For resting conditions, the general trend is higher power for Rest-Closed (4) than Rest-Open (5) except for core-auditory where Rest-Open (5) showed higher power than Rest-Closed (4) for non-musicians. This is in accordance with statistical results. As was explained above, there was a significant value for interaction of group by hemisphere for core-auditory sensor in the separate test of resting conditions.

3.2.2 Paired t-test for comparing amplitudes of auditory sensors

The procedure of the test was the same as in the alpha band. The beta band results showed that the differences between almost all pairs were significant, except for two pairs, Stream and

Rest-Open in the left hemisphere. All values can be seen in the table of results, appendix 4, table 1.

3.2.3 Vertex area

In the vertex area, the only significant result was for effect of Hemisphere (P<0.01). There was no general group difference here. All values can be seen in the table of results, appendix 1, table 2.

For separate test of music conditions, again Hemisphere showed significant difference (P<0.01) and also interaction of Hemisphere*Condition*Group (P<0.05) was significant. All values can be seen in the table of results, appendix 2, table 2.

As for separate test of resting conditions, just Hemisphere (P<0.05) significantly differed. All values can be seen in the table of results, appendix 3, table 2. Figure 10 illustrates the difference between groups separately for each hemisphere in the temporal area:

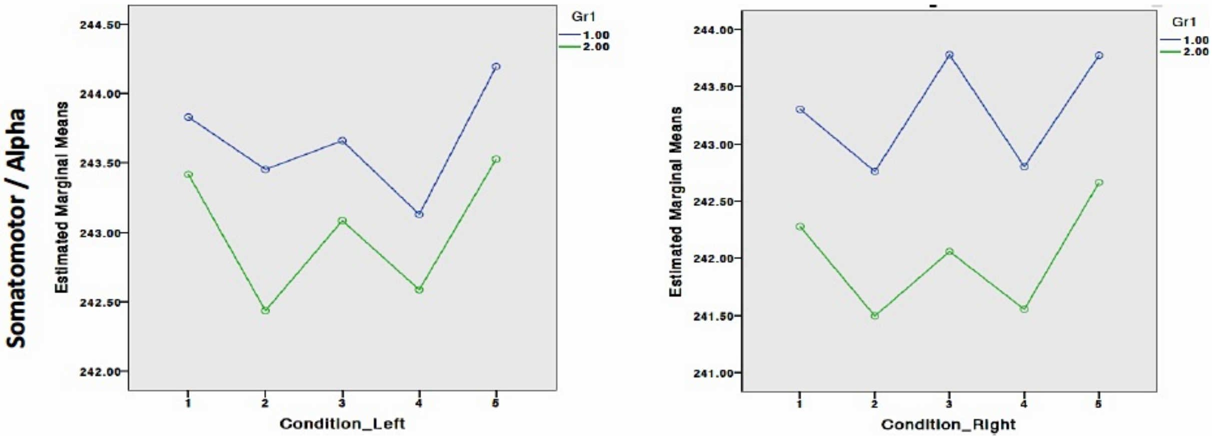

Figure 10. Beta band / Vertex area / Conditions in different hemisphere

The description of the elements in figure 10 is similar to figure 7 (See 3.1.1, paragraph 4). Based on figure above, in general, musicians (blue color) showed stronger beta values than non-musicians (green color) in both hemispheres.

For the three music conditions, Piazzolla (2) showed the lowest beta values in both hemispheres for both groups and Stream (1) power values were the highest except for the right hemisphere where for musicians RoS (3) had the highest power.

As for resting conditions, Rest-Open (5) showed stronger beta values than Rest-Closed (4) for both sensors, both hemispheres and both groups.

3.3 Low-Gamma band (30-45 Hz) MANOVAs results

3.3.1 Temporal area

Similar to the alpha and beta bands, there were no general group differences in the low-gamma band activity. There was not any significant result here. All values can be seen in the table of results, appendix 1, table 3.

For separate test of music conditions, again there was no significant result. All values can be seen in the table of results, appendix 2, table 3.

For separate test of resting conditions, The only significant result was for the effect of Condition ($P_{Anterior}<0.001$ & $P_{Core}<0.05$). All values can be seen in the table of results, appendix 3, table 3. Figure 9 illustrates the difference between groups separately for each hemisphere in the temporal area:

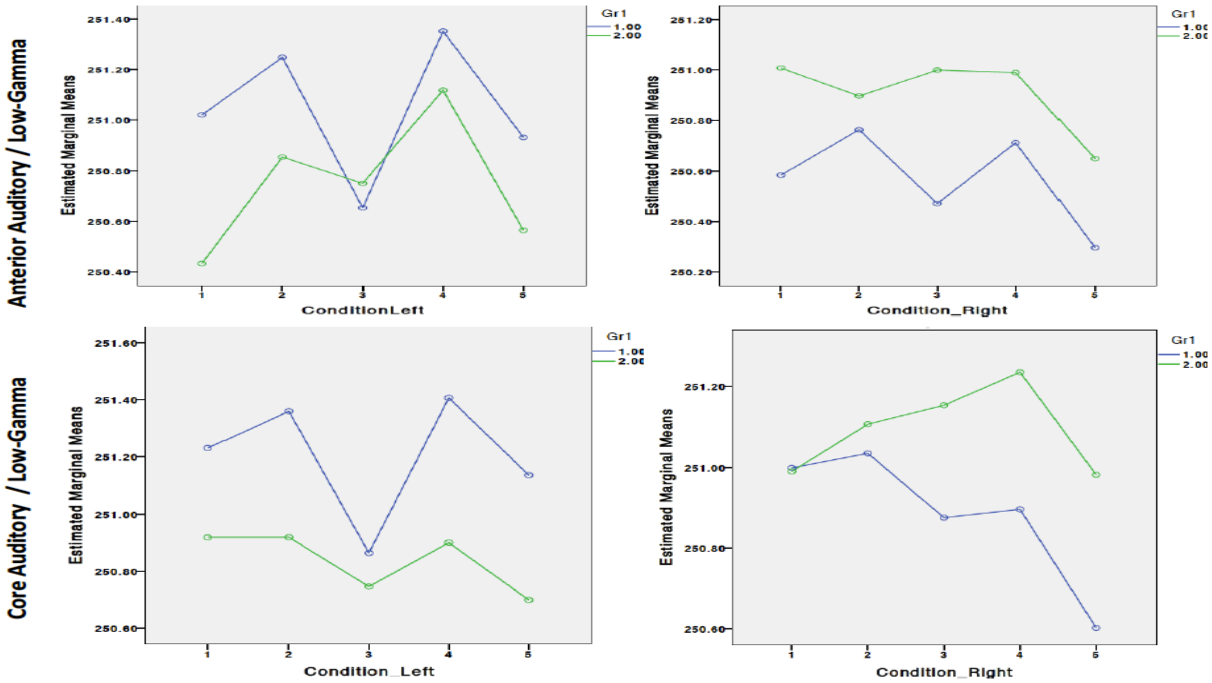

Figure 11. Low-Gamma band / Temporal area / Conditions in different hemisphere

The description of the elements in figure 11 is similar to figure 7 (See 3.1.1, paragraph 4). Based on figure above, in general, musicians (blue color) showed stronger low-gamma values than non-musicians (green color) in the left hemisphere whereas in the right hemisphere non-musicians seemed to have higher amplitudes.

For three music conditions, Piazzolla (2) showed the highest power for both sensors, both hemispheres and both groups except for non-musicians in the right hemisphere where RoS seemed to have the highest value.

As for resting conditions, Rest-Closed (4) showed stronger low-gamma values than Rest-Open (5) for both sensors, both hemispheres and both groups.

3.3.2 Paired t-test for comparing amplitudes of auditory sensors

The procedure of the test in the low-gamma band was the same as in the alpha band. There was no significant result in the gamma band except for Stream in the left hemisphere. All values can be seen in the table of results, appendix 4, table 1.

3.3.3 Vertex area

In the vertex area, there were significant differences for the effect of Hemisphere ($P<0.01$) and the effect of Condition ($P<0.01$). There was no general group difference here. All values can be seen in the table of results, appendix 1, table 3.

For separate test of music conditions, again Hemisphere showed significant difference ($P<0.01$) and also interaction of Hemisphere*Condition*Group ($P<0.05$) was significant. All values can be seen in the table of results, appendix 2, table 3.

As for separate test of resting conditions, there was no significant result. All values can be seen in the table of results, appendix 3, table 3. Figure 12 illustrates the difference between groups separately for each hemisphere in the temporal area

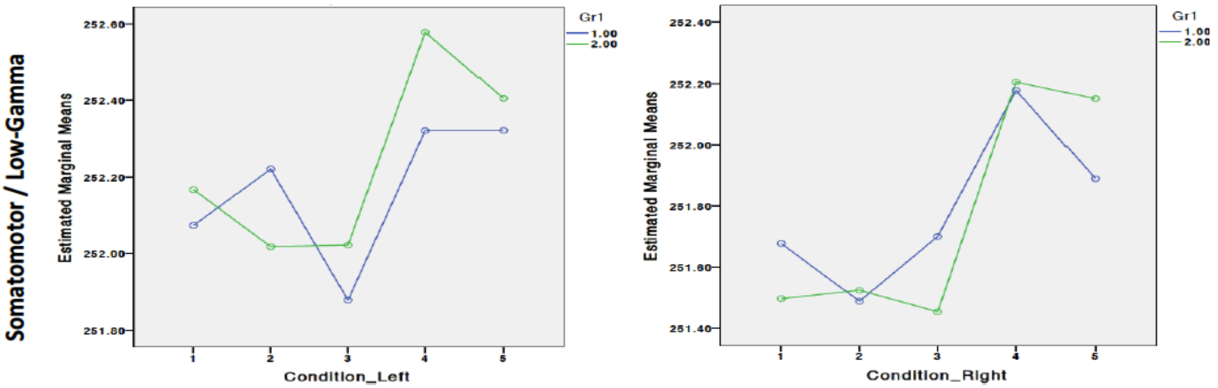

Figure 12. Low-Gamma band / Vertex area / Conditions in different hemisphere

The description of the elements in figure 12 is similar to figure 7 (See 3.1.1, paragraph 4). Based on figure above, no general interpretation can be made between musicians (blue color) and non-musicians (green color). The only interpretation can be higher values for non-musicians in resting conditions.

For three music conditions, Piazzolla (2) was the highest power in the left hemisphere for musicians whereas it had the lowest value in the right hemisphere. This is completely reverse for non-musicians; Piazzolla (2) had the lowest value in the left hemisphere and the highest in the right hemisphere.

As for resting conditions, Rest-Closed (4) showed higher values than Rest-Open (5) for both sensors, both hemispheres and both groups, except for musicians in the left hemisphere where both resting conditions (4&5) seemed to be equal.

3.3.4 Illustrating the group averages

To illustrate the group averages for all conditions of the experiment, different sensors in the different frequency bands, and different areas, we calculated the mean power values of each group in different frequency bands. So we had nine different sets, each one showing averaged value of one specific sensor in the desired frequency band. Figure 13 shows the comparison curves of the averaged power values for musicians and non-musicians:

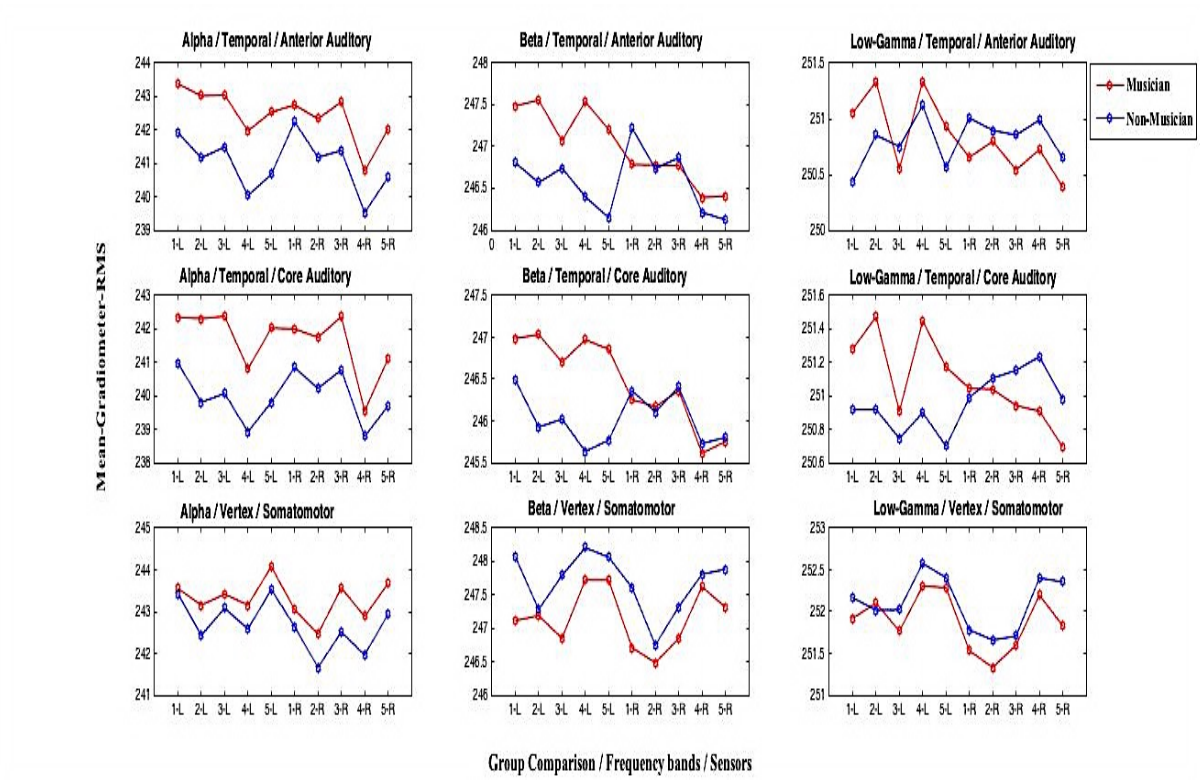

Figure 13. Group average curves / musicians vs. non-musicians

In figure 13, each frequency band is shown in separate columns and each sensor in three different rows. In each of the subplots, the x-axis stands for the different conditions and also different brain hemispheres. For instance, 1-L means the power value of the first music stimuli, Stream, in the left hemisphere and 5-R shows the value of the last stimuli, Rest-Open, in the right hemisphere. The y-axis shows the RMS mean values of the gradiometer channels of the selected sensors. The groups are shown in different colors, red for the musicians and blue for the non-musicians. Our interpretations of the figure above are as follows:

Based on the figure above, we can extract some interpretations. In general, in almost all frequency bands, musicians had higher power except for the last two subplots related to the power values of the somatomotor sensor in the beta and low-gamma bands where the non-musicians seemed to have stronger responses. Next, we interpret the above curves separately for music and resting conditions:

3.3.5.1 Interpretation of music conditions

In general, in almost all of music conditions, musicians showed higher powers in the left hemisphere. In the temporal areas, non-musicians had the highest power values in the right hemisphere whereas in the vertex area there seemed to be stronger responses in the left hemisphere.

Regarding the music conditions in each frequency band, musicians did not seem to show a very different trend in the alpha bands for all sensors, but there were more dissimilarities in the curves of both beta and low-gamma bands, with the highest power for Piazzolla, and the lowest power for RoS. On the other side, non-musicians showed a similar trend in the curves of both alpha and beta bands for all sensors, with the highest power for Stream (RoS seemed to have a slightly lower power than Stream) and the lowest power for Piazzolla. In the low-gamma band curves, non-musicians showed a change in the direction with a higher power in Piazzolla, in the left hemisphere.

3.3.5.2 Interpretation of resting conditions

As for the resting conditions, for musicians, there seemed to be higher power values in the left hemisphere of the temporal area in curves of all frequency bands. For non-musicians in the temporal area, curves of the alpha and beta bands seemed similar, and in the low-gamma band there was no common interpretation. In the vertex area, non-musicians mean power values seemed to be higher in the left hemisphere than in the right hemisphere for all frequency bands.

Concerning the differences between different resting conditions, for musicians and in the alpha band curve, Rest-Open seemed to have higher power than Rest-Closed whereas in the curves of the beta and low-gamma bands we can see an inverse trend, with a higher power for Rest-Closed than Rest-Open; however, this is not very clear for the curves of the right temporal and left vertex in the beta band. Non-musicians showed similar trends as musicians in the alpha band. In the beta and low-gamma bands, Rest-Closed seemed to have higher power than Rest-Open, except for the core-auditory (left and right) and somatomor (right) sensors.

4 DISCUSSION

The present study investigated the neural processing of music in the brain by means of MEG in musicians and non-musicians. There is very little empirical research in this specific field, consequently the methodology and analysis proved both challenging and instructive. Next, we discuss our findings corresponding to the hypotheses of the study:

4.1.1 Responses in different frequency bands differ for music listening vs. resting

One of the study's aims was to find the possible differences between neural processing of music stimuli of different genres and rest conditions in different frequency bands between musicians and non-musicians. Our results showed that the effect of condition was significant in all types of analyses. This could mean that the different music stimuli or, more specifically different genres, have different effects on the brain of all subjects regardless of their level of musicianship.

Our results also showed differences between two resting conditions in different frequency bands and brain areas of interest. We predicted stronger alpha for the resting with eyes-closed rather than eyes-open and we observed opposite direction. We also observed decrease of the power in the curves of power spectrum density in the beta and low-gamma bands, with higher amplitudes for musicians. This might be linked with cognitive/information processing in the beta band (Engel & Fries, 2010) and gamma band (Bhattacharya, Petsche, Feldmann & Rescher, 2001; Trainor, Shahin & Roberts, 2009).

4.1.2 Effect of musical expertise on brain oscillations

The main aim of this study was to scrutinize data in order to see differences between musicians and non-musicians. Our findings validated the outcomes of the reviewed literature (see 1.1.5) by showing the differences between subjects with and without musical training. As it was predicted, we observed differences between groups in all frequency bands and brain areas of interest, with higher power values in the left hemisphere of musicians. There was a significant group difference for Hemisphere in the beta band in the temporal area where the groups differed in the left hemisphere but not in the right hemisphere.

These predicted different responses for experts are in accordance with findings of very many other previous studies. There were left Heschl's gyrus and bilateral superior temporal gyrus interactions in musicians (Ono, Altmann, Matsuhashi, Mima, & Fukuyama, 2014) and the left cerebellum was strongly activated in musicians by using non-synchronic stimuli (Lu, Paraskevopoulos, Herholz, Kuchenbuch & Pantev, 2014). Additionally, Pantev, Paraskevopoulos, Kuchenbuch, Lu, and Herholz (2015) showed that musicians processed the alternation of the multisensory data differently in the auditory cortex.

4.1.3 Localization of neural correlates on brain areas and hemispheres

In our study we demonstrated that the oscillatory patterns differed for music and resting conditions. Those differences seemed to be influenced by musical expertise and were distributed differently in the temporal and vertex areas. We observed a significant lateralization to the left temporal areas for musicians in the beta band and only for resting condition. Additionally, there was a significant result for the interaction effect of Hemisphere*Condition*Group in the low-gamma band and for both temporal and vertex areas.

The expected left hemisphere dominance for musicians agrees with the previous researches. Bever and Chiarello (1974) showed the lateral differences in sound identification between musicians and non-musicians with more active left hemisphere in musicians. Additionally, an EEG study on neural oscillations synchronicity in the gamma band revealed left side superiority for musicians and right side dominance for non-musicians while they were listening to music and sounds (Bhattacharya, Petsche, Feldmann & Rescher , 2001). This might be due to the lateralization of musicians' brains and also more analytical way of listening to music than non-trained individuals.

4.1.4 Future research

One of the further analyses of this dataset could be checking the impact of the subjects' familiarity to music pieces and find a correlation between neural responses and degree of familiarity. This also might bring the idea of using each subject's self-selected songs rather than giving them the compulsory setting of the experiment. Familiarity to music can play a decisive role in similar experiments and evidence reveals that in one fMRI study, subjects showed greater activations in many brain areas while they were listening to familiar music rather than unfamiliar ones (Silva Pereira et al., 2011). Therefore, in order to have stronger responses from subjects, using familiar pieces as stimuli could be considered as a determinant factor in future.

Another point that might have made the current study more improved was to avoid mixing amateur musicians and non-musicians together. There might be difference between subjects with even one year of music instruction in comparison to a completely non-musically trained subject. This has been shown in one study by Lee, Skoe, Kraus and Ashley (2009) that the structure of auditory-sensory system differed effectively with length of experience in music. Consequently, there might have been more precise results if amateur musicians were put as a separate group and non-musicians were as our control group. Amateurs might have shown to some extent similar results to musicians and this might have been the main reason that the general group difference appeared to be non-significant in our results.

In addition, as evidence shows different results for musicians with different instruments (Krause, Schnitzler & Pollok, 2010), it might be worthwhile to compare musicians based on their instruments and see also the differences between various musical instruments, singing and playing one or more instruments.

Finally, regarding the participants, we did not consider gender differences in our study. One fMRI study showed that female and male subjects showed lateral differences in activated brain regions related to language while they were listening to stories (Kansaku, Yamaura & Kitaz, 2000) and another study claimed hemispherical differences in brain morphology of men and women (Good et al., 2001). Also females were more influenced by stress (Kogler, Gur & Derntl, 2015). Accordingly, with regards to further research it is recommended that the gender effect be considered as a variable.

5 CONCLUSION

Studying neural processing of music in the brain is a complex and gradual research that needs patience and exceptional multidisciplinary knowledge. The current study attempted to find significant differences between groups, conditions and hemispheres interactions and to answer our research questions. We found that different music stimuli had different effects in different frequency bands showing that musicians had generally increased responses compared to non-musicians, with left hemisphere dominance. In addition, observed differences regarding the location of the sensors and in general, auditory (temporal) and motor (vertex) areas behaved differently in different frequency bands and for both groups.

Further studies in this field could include correlation analyses between the same MEG data and computationally extracted musical features, fMRI data with similar settings, or the WII data representing the arousal/valence responses from participants to music. In short, the current study can be considered as a foundation for future work exploring neural differences as a function of musical training using neuroimaging techniques and naturalistic paradigms.

REFERENCES

Abrams, D. A., Ryali, S., Chen, T., Chordia, P., Khouzam, A., Levitin, D. J., et al. (2013). Inter-subject synchronization of brain responses during natural music listening. *European Journal of Neuroscience* , 1458–1469.

Alluri, V., Toiviainen, P., Jääskeläinen, I. P., Glerean , E., Sams , M., & Brattico , E. (2012). Large-scale brain networks emerge from dynamic processing of musical timbre, key and rhythm. *NeuroImage* , 3677-3689.

Angulo-Perkins, A., Aube, W., Peretz, I., Zatorre, R. J., Barrios, F. A., Armony, J. L., et al. (2014). Music listening engages specific cortical regions within the temporal lobes: Differences between musicians and non-musicians. *Elsevier* , 126-137.

Argo, J., Ma , M., & Kayser, C. (2014). Immersive Composition for Sensory Rehabilitation: 3D Visualisation, Surround Sound, and Synthesised Music to Provoke Catharsis and Healing. *Springer* , 134-149.

Argstatter, H. (2015). Perception of basic emotions in music: Culture-specific or multicultural? *Psychology of Music* , 1-17.

Benovoy, M., Dagher, A., Larcher, K., Salimpoor, V. N., & Zatorre, R. J. (2010). Anatomically distinct dopamine release during anticipation and experience of peak emotion to music. *Natural Neuroscience* , doi:10.1038/nn.2726.

Berridge, K. C., & Robinson, T. E. (2003). Parsing reward. *Trends in neurosciences , 26*, 507-513.

Bever, T. G., & Chiarello, R. J. (2009). Cerebral Dominance in Musicians and Nonmusicians. *The Journal of Neuropsychiatry and Clinical Neurosciences* , 94-97.

Blood, A. J., & Zatorre, R. J. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated reward and emotion . *PNAS , 98*, 11818-11823.

Burunat, I., Toiviainen, P., Alluri, V., Bogert, B., Ristaniemi, T., Sams, M., et al. (2016). The reliability of continuous brain responses during naturalistic listening to music. *NeuroImage* , 1-7.

Chen, X.-J., Hannibal, N., & Gold, C. (2015). Randomized Trial of Group Music Therapy With Chinese Prisoners: Impact on Anxiety, Depression, and Self-Esteem. *International Journal of Offender Therapy and Comparative Criminology* , 1-18.

Curran, T., Haughey, H. M., Hutchison, K. E., Frank, M. J., & Moustafa, A. A. (2007). Genetic triple dissociation reveals multiple roles for dopamine in reinforcement learning . *PNAS , 104*, 16311-16316.

de Lange, F. P., Jensen, O., Bauer, M., & Toni, I. (2008). Interactions between posterior gamma and frontal alpha/beta oscillations during imagined actions. *Frontiers in Human Neuroscience* , 1-12.

Engel, A. K., & Fries, P. (2010). Beta-band oscillations—signalling the status quo? *Current Opinion in Neurobiology* , 156-165.

Esfandiari, N., & Mansouri, S. (2014). The effect of listening to light and heavy music on reducing the symptoms of depression among female students. *Elsevier* , 211-213.

Fernández-Sotos, A., Fernández-Caballero, A., & Latorre, J. M. (2015). Elicitation of Emotions through Music: The Influence of Note Value. Springer.

Frank, M. J., O'Reilly, R. C., & Seeberger, L. C. (2004). By carrot or by stick: cognitive reinforcement learning in Parkinsonism. *Science , 306*, 1940-1943.

Garza-Villarreal , E. A., Wilson, A. D., Vase, L., Brattico, E., Barrios, F. A., Jensen, T. S., et al. (2014). Music reduces pain and increases functional mobility in fibromyalgia. *Frontiers in Psychology* , 1-10.

Gold, P. B., Frank, J. M., Bogert, B., & Brattico, E. (2013). Pleasurablemusicaffectsreinforcementlearningaccordingtothelistener. *Frontiers in psychology* , 1-19.

Hamalainen, M., Hari, R., Ilmoniemi, R. J., Knuutila, J., & Lounasmaa, O. V. (1993). Magnetoencephalography-theory, instrumentation, and applications to noninvasive studies of the working human brain. *Reviews of Modern Physics* , 413-505.

Hansen, P. C., Kringelbach, M. L., & Salmelin, R. (2010). *MEG: An introduction to methods.* Oxford : Oxford University Press.

Hasson, U., Malach, R., & Heeger, D. J. (2009). Reliability of cortical activity during natural stimulation. *Elsevier* , 40-48.

Hillier, A., Kopec, J., Poto, N., Tivarus , M., & Q. Beversdorf, D. (2015). Increased physiological responsiveness to preferred music among young adults with autism spectrum disorders. *Psychology of Music* , 1-15.

Koelsch , S. (2012). *brain & music.* West Sussex: Wiley-Blackwell.

Koelsch, S. (2015). Music-evoked emotions: principles, brain correlates, and implications for therapy. *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* , 193-201.

Kuyatt, C. E., & Taylor, B. N. (1994). NIST guidelines: TN 1297: Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results. From http://physics.nist.gov/Pubs/guidelines/appd.1.html

Leow, L.-A., Rinchon , C., & Grahn, J. (2015). Familiarity with music increases walking speed in rhythmic auditory cuing. *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* , 53-61.

Lopez, L., Jurgens, R., Diekmann, V., Becker, W., Ried, S., & Grozinger, B. (2003). Musicians versus Nonmusicians: A Neurophysiological approach. *Annals of the New York Academy of Sciences* , 124-130.

Lu, Y., Paraskevopoulos, E., Herholz, S. C., Kuchenbuch, A., & Pantev, C. (2014). Temporal Processing of Audiovisual Stimuli Is Enhanced in Musicians: Evidence from Magnetoencephalography (MEG). *Plos One* , 1-7.

Marin, M. M., & Bhattacharya, J. (2009). MUSIC INDUCED EMOTIONS: SOME CURRENT ISSUES AND CROSS-MODAL COMPARISONS. In J. H. Ferrero (Ed.), *Music and* (pp. 1-38). Nova Science Publishers, Inc.

Menon, V., & Levitin, D. J. (2005). The rewards of music listening: Response and physiological connectivity of the mesolimbic system. *Elsevier* , 175-184.

Mitterschiffthaler, M. T., Fu, C. H., Dalton, J. A., Andrew, C. M., & Williams, S. C. (2007). A Functional MRI Study of Happy and Sad Affective States Induced by Classical Music. *Wiley InterScience* , 1150-1162.

Ono, K., Altmann, C. F., Matsuhashi, M., Mima, T., & Fukuyama, H. (2014). Neural correlates of perceptual grouping effects in the processing of sound omission by musicians and nonmusicians. *Elsevier* , 25-31.

Pantev, C., Paraskevopoulos, E., Kuchenbuch, A., Lu, Y., & Herholz, S. C. (2015). Musical expertise is related to neuroplastic changes of multisensory nature within the auditory cortex. *European Journal of Neuroscience* .

Popescu, M., Otsuka, A., & Ioannides, A. A. (2004). Dynamics of brain activity in motor and frontal cortical areas during music listening: a magnetoencephalographic study. *Elsevier* , 1622-1638.

(2012). The auditory system. In D. Purves , G. J. Augustine, D. Fitzpatric, W. C. Hall, A.-S. LaMantia, & L. E. White, *Neuroscience* (Fifth ed., pp. 277-302). Massachusetts: Sunderland.

Ray , W. J., & Cole , H. W. (1985). EEG Alpha Activity Reflects Attentional Demands, and Beta Activity Reflects Emotional and Cognitive Processes. *Science* , 750-752.

Särkämö, T., & Soto, D. (2012). Music listening after stroke: beneficial effects and potential neural mechanisms. *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* , 266-281.

Salimpoor et al., V. N. (2013). Interactions Between the Nucleus Accumbens and Auditory Cortices Predict Music Reward Value. *Science , 340, 216, 306*, DOI: 10.1126/science.1231059.

Salimpoor, V. N., Zald, D. H., Zatorre, R. J., Dagher, A., & McIntosh, A. R. (2015). Predictions and the brain: how musical sounds become rewarding. *Trends in Cognitive Sciences* , 86-91.

Sarkamo , T., Laitinen, S., Tervaniemi, M., Numminen, A., Kurki, M., & Rantanen, P. (2012). Music, Emotion, and Dementia: Insight From Neuroscientific and Clinical Research. *Music and Medicine* , 153-162.

Thiede, A. (2014). Magnetoencephalographic (MEG) Inter-subject Correlation using Continuous Music Stimuli. Finland: Aalto University, School of Science.

Trainor , L. J., Shahin , A. J., & Roberts , L. E. (2009). Understanding the Benefits of Musical Training Effects on Oscillatory Brain Activity . *Annals of the New York Academy of Sciences* , 133-142.

Trainor, L. J., Shahin, A. J., & Roberts, L. E. (2009). Understanding the Benefits of Musical Training Effects on Oscillatory Brain Activity. *Annals of the New York Academy of Sciences* , 133-142.

Verrusioa , W., Andreozzia, P., Mariglianob, B., Renzi, A., Gianturco, V., Pecci, M. T., et al. (2014). Exercise training and music therapy in elderly with depressive syndrome: A pilot study vq. *Elsevier* , 614-620.

Vuilleumier, P., & Trost, W. (2015). Music and emotions: from enchantment to entrainment. *ANNALS OF THE NEW YORK ACADEMY OF SCIENCES* , 212-222.

Vuust, P., Ostergaard, L., Pallesen, K. J., Bailey, C., & Roepstorff, A. (2008). Predictive coding of music – Brain responses to rhythmic incongruity. *Cortex* , 80-92.

Welch, P. D. (1967). The Use of Fast Fourier Transformfor the Estimation of Power Spectra: A Method Based on Time Aver. aging Over Short, Modified Periodograms. *IEEE* , 70/73.

Zald, D. H., & Zatorre, R. J. (2011). Chapter 19, Music. In Taylor, Francis, & G. J. (Ed.), *The Neurobiology of Sensation and Reward.* CRC Press.

Zatorre, R. (2005). Music, the food of neuroscience? *Nature* , 312-125.

Zentner, M., Grandjean, D., & Scherer, K. R. (2008). Emotions Evoked by the Sound of Music: Characterization, Classification, and Measurement. *Emotion* , 494-521.

APPENDICES

APPENDIX 1: Tables of Results, Within-Subjects Effects

TABLE 1. Alpha band (8-12 Hz), tests of Within-Subjects Effects (Huynh-Feldt)

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	2.713	0.112
		Hemisphere*Group	1.000	1.844	0.186
		Condition	2.547	18.809	0.000
		Condition*Group	2.547	0.448	0.688
		Hemisphere* Condition	4.000	2.130	0.082
		Hemisphere* Condition*Group	4.000	0.744	0.564
	Core Auditory	Hemisphere	1.000	0.904	0.350
		Hemisphere*Group	1.000	2.217	0.149
		Condition	2.611	23.117	0.000
		Condition*Group	2.611	1.263	0.293
		Hemisphere* Condition	3.906	4.676	0.002
		Hemisphere* Condition*Group	3.906	0.832	0.505
Vertex	Somatomotor	Hemisphere	1.000	9.429	0.005
		Hemisphere*Group	1.000	1.995	0.170
		Condition	2.321	3.630	0.027
		Condition*Group	2.321	0.153	0.887
		Hemisphere* Condition	3.379	0.951	0.428
		Hemisphere* Condition*Group	3.379	1.131	0.344

TABLE 2. Beta band (13-30 Hz), tests of Within-Subjects Effects (Huynh-Feldt)

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	2.163	0.153
		Hemisphere*Group	1.000	3.501	0.073
		Condition	2.056	4.003	0.023
		Condition*Group	2.056	0.917	0.408

		Hemisphere* Condition	4.000	1.798	0.135
		Hemisphere* Condition*Group	4.000	0.464	0.762
	Core Auditory	Hemisphere	1.000	1.307	0.263
		Hemisphere*Group	1.000	4.453	0.045
		Condition	3.325	3.202	0.023
		Condition*Group	3.325	1.192	0.319
		Hemisphere* Condition	2.431	1.456	0.141
		Hemisphere* Condition*Group	2.431	1.013	0.381
Vertex	Somatomotor	Hemisphere	1.000	7.255	0.012
		Hemisphere*Group	1.000	1.004	0.326
		Condition	2.196	2.887	0.059
		Condition*Group	2.196	0.392	0.697
		Hemisphere* Condition	3.777	1.104	0.358
		Hemisphere* Condition*Group	3.777	2.122	0.088

TABLE 3. Low-Gamma band (30-45 Hz), tests of Within-Subjects Effects (Huynh-Feldt)

Brain Area	***Sensors***	***Interacting mode***	***df***	***F***	***P***
Temporal	Anterior Auditory	Hemisphere	1.000	0.420	0.523
		Hemisphere*Group	1.000	1.777	0.194
		Condition	3.377	2.225	0.083
		Condition*Group	3.377	0.544	0.674
		Hemisphere* Condition	4.000	1.473	0.216
		Hemisphere* Condition*Group	4.000	0.509	0.729
	Core Auditory	Hemisphere	1.000	0.017	0.898
		Hemisphere*Group	1.000	1.492	0.233
		Condition	3.699	1.202	0.315
		Condition*Group	3.699	0.258	0.892
		Hemisphere* Condition	3.354	0.963	0.421
		Hemisphere* Condition*Group	3.354	0.785	0.518
Vertex	Somatomotor	Hemisphere	1.000	6.956	0.014
		Hemisphere*Group	1.000	0.087	0.770
		Condition	2.943	4.373	0.007

		Condition*Group	2.943	0.252	0.856
		Hemisphere* Condition	3.779	2.399	0.059
		Hemisphere* Condition*Group	3.779	2.307	0.067

APPENDIX 2: Tables of Results, Within-Subjects Effects, Only Music

TABLE 1. Alpha band (8-12 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Music stimuli only

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	1.137	0.296
		Hemisphere*Group	1.000	1.851	0.185
		Condition	2.000	5.522	0.007
		Condition*Group	2.000	1.169	0.319
		Hemisphere* Condition	2.000	0.162	0.851
		Hemisphere* Condition*Group	2.000	1.498	0.233
	Core Auditory	Hemisphere	1.000	0.001	0.975
		Hemisphere*Group	1.000	1.176	0.288
		Condition	2.000	4.716	0.013
		Condition*Group	2.000	3.229	0.048
		Hemisphere* Condition	1.930	3.978	0.026
		Hemisphere* Condition*Group	1.930	1.090	0.342
Vertex	Somatomotor	Hemisphere	1.000	9.856	0.004
		Hemisphere*Group	1.000	2.233	0.147
		Condition	1.986	5.899	0.005
		Condition*Group	1.986	0.644	0.528
		Hemisphere* Condition	2.000	2.192	0.122
		Hemisphere* Condition*Group	2.000	2.417	0.099

TABLE 2. Beta band (13-30 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Music stimuli only

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	0.759	0.392
		Hemisphere*Group	1.000	3.437	0.075

		Condition	2.000	1.043	0.360
		Condition*Group	2.000	1.087	0.345
		Hemisphere* Condition	1.93	0.222	0.795
		Hemisphere* Condition*Group	1.937	0.912	0.406
	Core Auditory	Hemisphere	1.000	0.161	0.691
		Hemisphere*Group	1.000	3.172	0.087
		Condition	1.658	2.558	0.098
		Condition*Group	1.658	2.582	0.096
		Hemisphere* Condition	1.235	1.097	0.317
		Hemisphere* Condition*Group	1.235	1.389	0.254
Vertex	Somatomotor	Hemisphere	1.000	8.625	0.007
		Hemisphere*Group	1.000	0.168	0.685
		Condition	1.600	0.142	0.822
		Condition*Group	1.600	0.008	0.982
		Hemisphere* Condition	1.638	2.092	0.144
		Hemisphere* Condition*Group	1.638	3.914	0.035

TABLE 3. Low-Gamma band (30-45 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Music stimuli only

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	0.027	0.872
		Hemisphere*Group	1.000	1.838	0.187
		Condition	2.000	1.218	0.304
		Condition*Group	2.000	1.294	0.283
		Hemisphere* Condition	2.000	0.894	0.415
		Hemisphere* Condition*Group	2.000	0.865	0.427
	Core Auditory	Hemisphere	1.000	0.008	0.929
		Hemisphere*Group	1.000	0.804	0.378
		Condition	1.974	0.986	0.379
		Condition*Group	1.974	0.541	0.583
		Hemisphere* Condition	1.784	2.227	0.124
		Hemisphere* Condition*Group	1.784	0.226	0.773
Vertex	Somatomotor	Hemisphere	1.000	8.625	0.007

		Hemisphere*Group	1.000	0.168	0.685
		Condition	1.600	0.142	0.822
		Condition*Group	1.600	0.008	0.982
		Hemisphere* Condition	1.638	2.092	0.144
		Hemisphere* Condition*Group	1.638	3.914	0.035

APPENDIX 3: Tables of Results, Within-Subjects Effects, Only Resting

TABLE 1. Alpha band (8-12 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Rest conditions only

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	4.897	0.036
		Hemisphere*Group	1.000	1.379	0.251
		Condition	1.000	14.913	0.001
		Condition*Group	1.000	0.207	0.653
		Hemisphere* Condition	1.000	4.050	0.055
		Hemisphere* Condition*Group	1.000	0.148	0.703
	Core Auditory	Hemisphere	1.000	4.821	0.037
		Hemisphere*Group	1.000	3.133	0.088
		Condition	1.000	28.672	0.000
		Condition*Group	1.000	1.654	0.210
		Hemisphere* Condition	1.000	0.592	0.449
		Hemisphere* Condition*Group	1.000	0.474	0.497
Vertex	Somatomotor	Hemisphere	1.000	7.258	0.012
		Hemisphere*Group	1.000	1.371	0.252
		Condition	1.000	16.980	0.000
		Condition*Group	1.000	0.000	0.991
		Hemisphere* Condition	1.000	0.019	0.892
		Hemisphere* Condition*Group	1.000	0.234	0.633

TABLE 2. Beta band (13-30 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Rest conditions onl

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	4.160	0.052
		Hemisphere*Group	1.000	2.809	0.106
		Condition	1.000	2.572	0.121
		Condition*Group	1.000	0.024	0.879
		Hemisphere* Condition	1.000	0.722	0.403
		Hemisphere* Condition*Group	1.000	0.005	0.943
	Core Auditory	Hemisphere	1.000	3.923	0.058
		Hemisphere*Group	1.000	4.778	0.038
		Condition	1.000	0.044	0.836
		Condition*Group	1.000	0.381	0.542
		Hemisphere* Condition	1.000	0.029	0.867
		Hemisphere* Condition*Group	1.000	0.228	0.637
Vertex	Somatomotor	Hemisphere	1.000	5.132	0.032
		Hemisphere*Group	1.000	0.691	0.413
		Condition	1.000	0.055	0.817
		Condition*Group	1.000	0.078	0.782
		Hemisphere* Condition	1.000	0.033	0.858
		Hemisphere* Condition*Group	1.000	2.007	0.168

TABLE 3. Low-Gamma band (30-45 Hz), tests of Within-Subjects Effects (Huynh-Feldt), Rest conditions only

Brain Area	*Sensors*	*Interacting mode*	*df*	*F*	*P*
Temporal	Anterior Auditory	Hemisphere	1.000	1.476	0.235
		Hemisphere*Group	1.000	1.285	0.267
		Condition	1.000	15.371	0.001
		Condition*Group	1.000	0.018	0.895
		Hemisphere* Condition	1.000	0.377	0.545
		Hemisphere* Condition*Group	1.000	0.347	0.561
	Core Auditory	Hemisphere	1.000	0.141	0.711

		Hemisphere*Group	1.000	2.140	0.155
		Condition	1.000	5.508	0.027
		Condition*Group	1.000	0.064	0.803
		Hemisphere* Condition	1.000	0.045	0.833
		Hemisphere* Condition*Group	1.000	0.007	0.932
Vertex	Somatomotor	Hemisphere	1.000	3.495	0.073
		Hemisphere*Group	1.000	0.006	0.937
		Condition	1.000	2.163	0.153
		Condition*Group	1.000	0.031	0.862
		Hemisphere* Condition	1.000	0.403	0.531
		Hemisphere* Condition*Group	1.000	2.317	0.140

APPENDIX 4: Tables of Results, T-Test of sensor location

TABLE 1. Paired sample tests between auditory sensors

Frequency Band	*Conditions*	*Pairs*	*df*	*t*	*P*
Alpha	1 L	Pair 1	27	-3.292	0.003
	1 R	Pair 2	27	-3.857	0.001
	2 L	Pair 3	27	-3.448	0.002
	2 R	Pair 4	27	-2.792	0.009
	3L	Pair 5	27	-4.267	0.000
	3R	Pair 6	27	-1.829	0.079
	4L	Pair 7	27	-3.705	0.001
	4R	Pair 8	27	-2.843	0.008
	5L	Pair 9	27	-2.649	0.013
	5 R	Pair 10	27	-2.926	0.007
Beta	1 L	Pair 1	27	-1.991	0.057
	1 R	Pair 2	27	-3.010	0.006
	2 L	Pair 3	27	-2.189	0.037
	2 R	Pair 4	27	-3.297	0.003
	3L	Pair 5	27	-3.290	0.003
	3R	Pair 6	27	-2.138	0.042
	4L	Pair 7	27	-2.880	0.008

	4R	Pair 8	27	-2.217	0.035
	5L	Pair 9	27	-1.842	0.076
	5 R	Pair 10	27	-2.063	0.049
Low-Gamma	1 L	Pair 1	27	2.328	0.028
	1 R	Pair 2	27	1.108	0.277
	2 L	Pair 3	27	0.438	0.665
	2 R	Pair 4	27	1.398	0.173
	3L	Pair 5	27	0.588	0.561
	3R	Pair 6	27	1.338	0.192
	4L	Pair 7	27	-0.384	0.704
	4R	Pair 8	27	1.077	0.291
	5L	Pair 9	27	0.776	0.445
	5 R	Pair 10	27	1.797	0.084

APPENDIX 5: Tables of Results, Test of contrast between conditions

TABLE 1. Tests of contrasts between different conditions of the experiment

Frequency band	***Sensor***	***Interacting mode***	***df***	***F***	***P***
Alpha	Anterior Auditory	Level 1 vs. level 5	1	21.130	0.000
		Level 2 vs. level 5	1	6.474	0.017
		Level 3 vs. level 5	1	5.499	0.027
		Level 4 vs. level 5	1	14.913	0.001
	Core Auditory	Level 1 vs. level 5	1	10.505	0.003
		Level 2 vs. level 5	1	3.595	0.069
		Level 3 vs. level 5	1	6.002	0.021
		Level 4 vs. level 5	1	28.672	0.000
	Somatomotor	Level 1 vs. level 5	1	0.969	0.334
		Level 2 vs. level 5	1	8.184	0.008
		Level 3 vs. level 5	1	1.032	0.319
		Level 4 vs. level 5	1	16.980	0.000
Beta	Anterior Auditory	Level 1 vs. level 5	1	10.872	0.003
		Level 2 vs. level 5	1	11.609	0.002
		Level 3 vs. level 5	1	3.489	0.073
		Level 4 vs. level 5	1	2.572	0.121

	Core Auditory	Level 1 vs. level 5	1	8.077	0.000
		Level 2 vs. level 5	1	0.289	0.595
		Level 3 vs. level 5	1	2.951	0.098
		Level 4 vs. level 5	1	0.044	0.836
	Somatomotor	Level 1 vs. level 5	1	0.962	0.336
		Level 2 vs. level 5	1	6.170	0.020
		Level 3 vs. level 5	1	2.667	0.115
		Level 4 vs. level 5	1	0.055	0.817
Low-Gamma	Anterior Auditory	Level 1 vs. level 5	1	0.597	0.447
		Level 2 vs. level 5	1	3.364	0.078
		Level 3 vs. level 5	1	0.315	0.580
		Level 4 vs. level 5	1	15.371	0.001
	Core Auditory	Level 1 vs. level 5	1	1.709	0.203
		Level 2 vs. level 5	1	2.093	0.160
		Level 3 vs. level 5	1	0.095	0.760
		Level 4 vs. level 5	1	5.508	0.027
	Somatomotor	Level 1 vs. level 5	1	3.210	0.085
		Level 2 vs. level 5	1	5.847	0.023
		Level 3 vs. level 5	1	5.670	0.025
		Level 4 vs. level 5	1	2.163	0.153