The role of musical expertise in the perception of music and movement: an EEG study of neural oscillatory activity

Johanna Tuomisto
Master's Thesis
Department of Psychology
University of Jyväskylä
December 2015

ACKNOWLEDGEMENTS

I would like to thank my supervisors Tiina Parviainen, Mari Tervaniemi and Hanna Poikonen for good guidance and inspiring encouragement throughout the whole project. Also, many thanks belongs Risto-Matti for his patient listening and persistent warm support.

UNIVERSITY OF JYVÄSKYLÄ

Department of Psychology

TUOMISTO, JOHANNA: The role of musical expertise in the perception of music and movement: an EEG study of neural oscillatory activity

Master's thesis, 30 pp., 3 appendices

Supervisors: Tiina Parviainen, PhD; Research director Mari Tervaniemi; Hanna Poikonen, M.Sc.

Psychology

December 2015

Previous research has shown that musical expertise has impact on perception, especially in the auditory domain. Musicians succeed better in music-related tasks and seem to recruit broader brain areas during them. Most of the research on expertise has focused on music perception, but extensive musical training and experiences might impact also to other domains, for instance, to perception of movement. This seems natural when thinking of the nature of learning to play music: visual information of notes is changed into auditory sounds through carefully controlled motor actions. This fundamentally multisensory transaction also states the need of studying the effect of musical expertise on multimodal perception.

The present study investigates these matters in the level of neural oscillatory activity. Electroencephalography (EEG) was measured from adult musicians ($N = 13$) and controls with no professional musical background ($N = 14$) in rest and during continuous music and dance stimulus (duration app. 1 min). Stimuli presentation included three conditions: (1) music listening (audio only), (2) watching dance performance from a video (visual only), (3) music and dance stimuli presented simultaneously as an entity (audio-visual). Power spectral densities of alpha- and beta-band were computed and the obtained levels were compared statistically between the groups and conditions.

Results suggest that musicians have slightly modified alpha-band activity on EEG sensors over parieto-occipital brain area in audio-visual condition. This might indicate differences in attentional processes based on the research of the inhibitory role of alpha oscillation. On the other hand, previous research has linked parieto-occipital area to the integration of multisensory stimulus. Taken together, the present study alludes to a new area in research of how musical expertise effects on perceptual processing by extending the evidence to multisensory perception and the oscillatory activity of the brain.

Keywords: musical expertise, neural oscillation, music perception, movement perception, multisensory perception, electroencephalography

JYVÄSKYLÄN YLIOPISTO

Psykologian laitos

TUOMISTO, JOHANNA: The role of musical expertise in perception of music and movement: an EEG study of neural oscillatory activity

Pro gradu –tutkielma, 30 s., 3 liites.

Ohjaajat: Tiina Parviainen, PsT; Tutkimusjohtaja Mari Tervaniemi; Hanna Poikonen, DI

Psykologia

Joulukuu 2015

Aiempi tutkimus on osoittanut, että musiikillisella asiantuntijuudella on vaikutuksia havaitsemiseen, erityisesti kuuloaistissa. Muusikot suoriutuvat paremmin musiikillisista tehtävistä, joiden aikana heidän aivonsa myös aktivoituvat laajemmin ei-muusikoihin verrattuna. Suurin osa musiikillisen asiantuntijuuden tutkimuksesta on keskittynyt musiikin havaitsemiseen, mutta intensiivinen instrumentin harjoittelu sekä laajamittaiset musiikilliset kokemukset voivat vaikuttaa myös muihin aistipiireihin, kuten liikkeen havaitsemiseen. Tämä vaikuttaa todennäköiseltä ajatellessa musiikillisen instrumentin harjoittelun moniaistista luonnetta: nuottien visuaalinen muoto muunnetaan auditiivisiksi ääniksi hienovaraisten motoristen liikkeiden kautta. Tämä perustelee tarpeen laajentaa musiikillisen asiantuntijuuden vaikutuksien tutkimusta myös moniaistiseen havaitsemiseen.

Tämä tutkielma lähestyy näitä aiheita aivojen sähköisistä oskillaatioista käsin. Aikuisten muusikkojen (N = 13) ja ei-muusikkojen (N = 14) aivosähkökäyrää (EEG) mitattiin heidän kuunnellessaan musiikkia ja katsellessaan tanssia videolta (kesto n. 1 min). Ärsykkeet esitettiin kolmena aistimodaalisesti erilaisena tilanteena: (1) musiikin kuunteleminen, (2) tanssiesityksen katsominen videolta, (3) musiikin kuunteleminen ja tanssiesityksen katsominen samanaikaisesti moniaistisena tilanteena. Aivojen rytmistä aktiivisuutta mitattiin laskemalla alfa- ja beeta-oskillaatioiden tehospektrit (*eng.* power spectrum density), ja ryhmien tuloksia verrattiin tilastollisesti.

Kun musiikillinen ja visuaalinen ärsyke esitettiin samanaikaisesti moniaistisena kokonaisuutena, tulokset osoittivat viitteitä ryhmäeroihin alfa-oskillaatioiden tehossa päälaenlohkon ja takaraivolohkon raja-alueilla. Tämä voitaisiin tulkita tarkkaavuuden alaisten prosessien eroiksi alfa-oskillaation inhibitorisen rooliin perustuen. Toisaalta aiempi tutkimus on löytänyt todisteita em. aivoalueen aktivaation olevan yhteydessä moniaistiseen integraatioon. Tässä esitelty tutkimus antaa uusia suuntia musiikillisen asiantuntijuuden tutkimukselle laajentamalla sitä aivojen rytmisen toiminnan ja moniaistisen havaitsemisen alueelle.

Avainsanat: musiikillinen asiantuntijuus, neuraalinen oskillaatio, musiikin havaitseminen, liikkeen havaitseminen, moniaistinen havaitseminen, elektroenkefalogrammi

CONTENTS

1. INTRODUCTION

In the past few decades, the rhythmic activity of the brain has been a growing field of interest in cognitive neuroscience (Basar, Basar-Eroglu, Karakas, & Schürmann, 2001). Compared to event-related potential (ERP) studies, the continuous rhythmic activity has been considered to give a better sight to how the brain works in constantly changing environment full of overlapping continuous stimuli. The pattern of the oscillatory activity in the brain does not only change regarding to the state of consciousness but is varying in everyday wakeful situations. Still, it is unresolved whether specific patterns in the rhythmic activity have distinct psychological counterparts in behavior and whether specific sensorimotor, perceptual or cognitive functions can define these patterns (Engel & Fries, 2010).

These findings of cognitive neuroscience have been notified also in the study of music processing. Music psychology has long been interested on how music perception is formed and whether individual differences have an effect to it. As a rich and complex stimulus, music offers a unique frame to investigate brain organization and brain plasticity, especially in the case of acquired musical skills (Peretz & Zatorre, 2005; Strait & Kraus, 2014). Most of the brain research involving music has concentrated on imaging and localizing the areas related to music perception or searching for altered event-related potentials when listening to simple music stimuli, e.g. a short melody or a chord sequence. Only recently brain studies have taken the step to use continuous music, which is closer to the natural condition of experiencing music. Furthermore, too little is known about the functional relation of natural music perception and oscillatory activity of the brain. The present study wants to converge this subject by investigating the rhythmic activity of the brain during stimulus conditions of music listening and dance observing, another form of continuous stimulus. Perception of music and movement are investigated both separately and simultaneously in a multisensory condition with a specific interest on the role of musical expertise in these perceptual processes.

1. 1. EEG and brain oscillations

Electroencephalography (EEG) is a non-invasive brain imaging method with relatively low spatial resolution, but with an excellent temporal accuracy. EEG measures electrical activity of the cortical brain with electrodes placed on the scalp. Brain cells communicate through electrical impulses creating synchronized activation in neural populations and networks throughout the brain. This is possible due to their functional feature to gather voltage inside resulting in resting potential. When the resting membrane potential is decreased, due to changes in ionic concentration, up to certain threshold, action potential is generated (i.e. the cell 'fires'). Neurotransmitters are released to the synaptic cleft that may cause similar cascade in the next neuron. If the released neurotransmitters bind to the membrane of the post-synaptic cell, they can cause potential in it. EEG measures these post-synaptic potentials through electrodes placed on the scalp (Luck, 2005). Every electrode reflects the underlying electric field by recording its electric potential difference to the selected reference. As the neural activity fluctuates, the signal peaks up and down creating a wave-like oscillation.

Frequency of brain oscillation has been known for decades to vary in different states of consciousness and be modulated by sensory stimuli (Loomis, 1936; Adrian, 1950). These event-related changes in frequency can be presented as decreases and increases of power in given frequency bands, which are considered to rise from either decrease or increase of synchronized activity of underlying neuronal populations. The usual method to study this phenomenon has been named as event-related desynchronization (ERD) and event-related synchronization (ERS) (Pfurtscheller & Lopes da Silva, 1999), which reflect these changes in synchronized activity related to relatively short stimulus events. Accumulative evidence has shown that ERD or ERS in specific frequency bands occur consistently during specific cognitive tasks (Wang, 2010). Nevertheless, it is rarely studied how power is distributed over certain frequency ranges related to longer periods of stimulation.

The first spontaneous neural rhythmic activity ever measured was posterior alpha (with a frequency around 10 Hz), which is modulated simply by opening and closing eyes (Berger, 1929). Findings of next few decades (e.g. Adrian & Matthews, 1934) created an idea that alpha oscillation would function as 'an idling' rhythm occurring in a rest but alert brain state (Mulholland, 1995). In a contradiction to this, later research has revealed more diverse and active role of alpha oscillations in the functional brain (Basar, Basar-Eroglu, Karakas, & Schürmann, 2001). In addition to posterior alpha, oscillatory activity in alpha range has been recorded in several locations on the cortical surface, including frontal and prefrontal areas (Nunez, Wingeier, & Silberstein, 2001). Desynchronization in alpha band has been connected to excitability of cortex, especially in motor cortex in central brain areas (Rau, Plewnia, Hummel, & Gerlof, 2003). Alpha ERD has been related also with general attention demands, such as alertness and expectancy (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998).

Beta activity in the frequency range of 15-30 Hz was also found in the early times of EEG studies, and has been classically related to sensorimotor functions (Pfurtscheller, Stancák Jr., & Neuper, 1996). Indeed, several studies have shown that beta band oscillations rise during voluntary movement (Sanes & Donoghue, 1993) and steady contraction (Kilner, Baker, Salenius, Jousmäki, Hari, Lemon, 1999). Beta-band activity has been found to decrease during movement in the sensorimotor cortex located in central brain areas, where the oscillation is typically centered around 20 Hz (Salmelin, Hämäläinen, Kajola, & Hari, 1995). In addition, beta-band activity has been found to systematically decrease when only imaging motor movements (de Lange, Jensen, Bauer, & Toni, 2008), or even when observing other people performing an action (Hari, Forss, Avikainen, Kirveskari, Salenius, & Rizzolatti, 1998).

1. 2. Expertise in the brain

Human abilities to gain knowledge and acquire new skills rest on the functional feature of the brain to change. Sensory and motor experiences alter the brain, of which effects are seen in structural and functional as well as in behavioural level (Kolb & Gibb, 2011). Expertise offers a valuable opportunity to study how experience or knowledge from a certain field modifies the brain. In the visual domain, effect of expertise in the brain has been demonstrated in several areas such as birds, cars, dogs, and fingerprints (for review see Harel, Kravitz, & Baker, 2013). In addition to experience-dependent changes in perceptual processing, the acquisition of expertise contains gaining of conceptual knowledge from the field of interest (Harel, Kravitz, & Baker, 2013). This indicates that learning to recognize and categorize different features in expert level includes not only due to sensory exposure, but also cognitive processing. Expertise seems to have even more broad impact on behaviour, since experts have been claimed to differ from novices in various terms: knowledge, effort, recognition, analysis, strategy, memory use, monitoring (Hill & Schneider, 2006).

Musicians provide a good model for studying experience-dependent auditory processing in humans (Strait & Kraus, 2014). Previous exposure to music and listener's implicit knowledge about musical rules of that culture generates expectations, which modulate music perception (Zatorre & Salimpoor, 2013). Though this concerns every human living in some musical culture, the level of music exposure and musical actions are much higher in musicians. A body of evidence indicates that brain structures of musicians differ from non-musicians (Gaser & Schlaug, 2003; Schlaug, Jäncke, Huang, Steiger, & Steinmetz, 1995), assumingly resulting from intense music-involved experiences. Compared to non-musicians, musicians have faster and more accurate pitch discrimination (Tervaniemi, Just, Koelsch, Widmann, & Schröger, 2005), and they show broader brain activation during rhythm perception (Limb, Kemeny, Ortigoza, Rouhani, & Braun, 2006) and music listening (Angulo-Perkins, Aubé, Peretz, Barrios, Armony, & Concha, 2014).

In addition, expertise in music has been related to changes in neural networks. Evidence implies that musicians recruit cortical frontal areas in a greater degree during music-related task compared to non-musicians, probably reflecting top-down strategies (Chen, Penhune, & Zatorre, 2008). It has also been shown that when people train to play a musical instrument, the auditory-motor linkages in their brain are strengthened (for review see Jan-Maes, Leman, Palmer, & Wanderley, 2014) indicating stronger relation between music and motion in musicians.

1. 3. Perception of music

Music has universally recognized ability to elicit powerful human experiences. Keeping that in mind, it is not a surprise that music enhances activity in several cortical areas, including sensorimotor systems, memory and cognitive systems, and social/emotional areas (Trainor & Unrau, 2012; Alluri, Toiviainen, Jääskeläinen, Glerean, Sams, & Brattico, 2012). As these brain imaging studies imply, music perception involves a multitude of perceptual and cognitive mechanisms that are not yet fully understood. When a sound reaches the eardrum, it generates a complex chain of mechanical, chemical and neural events from cochlea to brain cortex. Before ending up as a unified perception, sound passes functionally segregated subsystems for processing various features from it. Most of the recent research on music perception has concentrated on finding neural correlates of these specific extracted features in music stimulus. According to widely acknowledged neuropsychological theory, melody and temporal structures of music are processed independently in the brain (Peretz & Zatorre, 2005). Processing of pitch and melody information is related mainly to auditory cortex (Patterson, 2002), while also motor areas of the cortex evidently contribute to the perception of temporal features in music (Janata & Grafton, 2003).

How these perceptual processes are represented in the brain can be studied by recording the cortical oscillatory activity described earlier. Research on music and brain oscillations has showed changes in alpha-band activity during natural music listening (Petsche, Kaplan, von Stein, & Filz, 1997; Wu, Zhang, Ding, Li, & Zhou, 2013). Music listening has also been linked to increased power of beta-band activity (Nakamura, Sadato, Oohashi, Nishina, Futamoto, & Yonekura, 1999). Nakamura et al. (1999) also measured alpha-band activation during music listening, but found significant power enhancement only in beta-band range, which implies that the results concerning occurrence of alpha- and beta-band activity during music listening and their role in music perception are still ambiguous. Since music perception and brain organization has been proved to differ in musical experts, it is also relevant to compare the location of music-enhanced brain activity in musicians and non-musicians. In the expertise study of Mikutta, Maissen, Altorfer, Strik, and Koenig (2014) the brain activity of professional musicians and amateur musicians during music listening showed no significant group difference in the alpha- or beta-band ranges in overall comparison, but location of increased rhythmic power in these frequencies revealed to be different. Musicians showed higher alpha and beta power in the frontal regions, while a discovered alpha enhancement in non-musicians was centered in the occipital areas. In another study with a music perception task, the location of increased alpha power revealed to differentiate the groups: musicians showed alpha peak in frontal-central regions compared to non-musicians (Maslennikova, Varlamov, & Strelets, 2015).

1. 4. Perception of movement

Evidence from brain imaging studies clearly shows that human motor cortex and parietal lobe is activated not only in the execution of a motor task, but also during action observation (for review see Rizzolatti, Fogassi, & Gallese, 2001). In electrophysiological studies, observation of actions has been related to desynchronization of alpha and beta band oscillations (Meirovitch, Harris, Dayan, Arieli, & Flash, 2015). This supports the theory of *embodied cognition*, which claims that all aspects of cognition, including perception, are based on sensory-motor system because the brain receives all the stimuli from external world through a sensing body (Borghi & Cimatti, 2010). This theory has also been applied to music perception as a concept of embodied music cognition, which emphasizes the role of the closed overlap of action and perception (Jan-Maes, Leman, Palmer, & Wanderley, 2014). It could be assumed that the level of embodiment in music perception would be higher in musicians, since the involvement of their motor cortex and action-related neural structures are shown to be more active during music listening task compared to non-musicians (Jan-Maes, Leman, Palmer, & Wanderley, 2014; Sherwin & Sajda, 2013). In a study on musical expertise, alpha-band activation in central brain sites differentiated musicians from controls during music listening, but not when visual stimulus was involved (Hadjidimitriou, Zacharakis, Doulgeris, Panoulas, Hadjileontiadis, & Panas, 2010). This creates an interesting theoretical frame to investigate and to compare music and movement perception especially in musical experts. Furthermore, another field of study is the integrative multimodal perception, of which musical experience has also been showed to have significant modifying effects (for review see Love, Pollick, & Petrini, 2012).

1. 5. Aims of the study

The general aim of this study is to investigate brain activity during rest and perception of continuous music and dance, and the role of musical expertise as a modifying factor in it. As presented earlier, brain activity is evidently altered during music listening (Trainor & Unrau, 2012; Alluri, Toiviainen, Jääskeläinen, Glerean, Sams, & Brattico, 2012) and during action observation (Rizzolatti, Fogassi, & Gallese, 2001) independent from musical background. However, the evidence concerning the nature of changes in brain activation related to music and movement perception is scattered. In order to be able to follow changes in neural activation during maximally natural perceptual situation, the changes in oscillatory pattern during continuous perception of music and dance are studied. Even more, musical expertise has been proved to modify separate processes of music perception (e.g., Tervaniemi, Just, Koelsch, Widmann, & Schröger, 2005; Limb, Kemeny, Ortigoza, Rouhani, & Braun, 2006), but more evidence is needed to understand how this is reflected in brain oscillations. In the present study, musicians are expected to differ from controls in brain activity during music perception based on this previous research of the effect of musical expertise. Concerning the level of dance expertise, the brain activity of groups is assumed not to differ during the perception of dance movement. Nonetheless, musical expertise has been related to altered activity in action-related neural networks as presented earlier, which might effect also in their perceptual processes when watching dance movements. For this reason, the brain activity during music and dance stimulus is also compared to rest condition in present study. Furthermore, a condition presenting music and dance stimulus together is included to the experiment for investigating brain activity during multimodal perception of music and dance, and the effect of musical expertise on it.

The first aim is to study group differences between musicians and non-musicians in the rhythmic activity of the brain during rest and stimulus conditions of (1) listening to music, (2) watching dance from a video, and (3) music stimulus combined with the dance stimulus. Second, brain activity during rest and stimulus conditions is compared within the groups, to reveal possible differences between perceptual processes of music and movement. Third, the brain activity is studied from different scalp locations to examine the spatial differences in oscillatory level during music and movement perception.

Brain activity is investigated with EEG from two frequency ranges: alpha-band and beta-band ranges. Power of these frequency bands is computed from EEG data recorded from three different scalp locations: frontal, central, parieto-occipital. Alpha-band power usually occurs as a clear-cut peak (around 10 Hz), which is searched individually and studied. Beta-band power is studied in relevantly narrow range (17-23 Hz), because action observation has been related to the activation around 20 Hz (Rizzolatti, Fogassi, & Gallese, 2001). Beta power is expected to increase during music listening, according to the results of Nakamura, Sadato, Oohashi, Nishina, Futamoto, and Yonekura (1999). Previous studies on musical expertise have discovered that professional musicians show increased alpha-band activity in frontal brain locations during music listening (Mikutta, Maissen, Altorfer, Strik, & Koenig, 2014; Maslennikova, Varlamov, & Strelets, 2015). In the present study, similar group differences are expected to find in stimulus conditions containing music, and especially in the condition of plain music stimulus without the dance video. Since alpha ERD is related to cortical excitability especially in motor cortex (Rau, Plewnia, Hummel, & Gerlof, 2003), and the motor cortex of musicians is activated more than in non-musicians while listening to music (Jan-Maes, Leman, Palmer, & Wanderley, 2014; Hadjidimitriou, Zacharakis, Doulgeris, Panoulas, Hadjileontiadis, & Panas, 2010), the power changes in alpha-band activity located in central brain regions might stand out to differentiate professional musicians from non-musicians. Also, the oscillatory activity in the beta range has been linked to those areas (e.g. Salmelin, Hämäläinen, Kajola, & Hari, 1995), therefore the levels of beta-band activity in central or posterior areas might to reveal differences between the groups.

2. MATERIAL AND METHODS

2. 1. Subjects

Thirty-nine young adults participated in the study. Subjects were recruited with different requirements concerning their background in music. This was done to form two groups: ‘Musician group’ consisted of twenty professional musicians (6 males and 14 females), and ‘Control group’ included nineteen participants (5 males and 14 females) with no professional expertise in music. Moreover, none of the participants had any professional level of expertise in dance. Because the recruitment was mainly done through networks of universities in Helsinki area, most of the subjects were undergraduates. Students to become professional musicians were accepted to participate, because all of them were expected to have strong background in music even before professional studies. This assumption was verified with a questionnaire concerning their background in music and dance. Also, none of them reported hearing loss, history of neurological illnesses, or eye refractive error uncorrectable by glasses. Age of the subjects varied from 20 to 37 years, with the mean of 25 years in both groups. All the subjects were studying in or graduated from university. Musicians were majoring in one instrument or studying music education, where studies include playing various instruments. Subjects in control group had no professional background in music or dance, though three of them reported having music and/or dance as a regular hobby. In addition, a group of professional dancers participated in the study, but the results from this group are reported elsewhere.

2. 2. Stimuli

Stimuli of the experiment included excerpts of continuous music presented via headphones and parts of dance choreography presented in video clips via monitor. Music and dance stimuli formed together an artistic entity, which was presented to the participants in three conditions: auditory, visual, and audio-visual. The order of conditions was randomized to avoid the effect of order in results. The whole stimulus presentation (with one possible order of conditions) is depicted in Figure 1. Each stimulus condition consisted of 20 stimulus extracts, which were displayed respectively from 1 to 20. Between the extracts there was a short pause (app. < 1 sec) in the presentation. Stimulus conditions were named after their content. The condition ‘Music’ consisted of music stimulus alone, while ‘Dance’ included dance stimulus as a silent video. In the condition ‘MusicDance’ music and dance stimulus were presented simultaneously as a combination. Duration of each stimulus condition was app. 16 minutes, and between them subjects was given an opportunity to take a pause.

Music excerpts were taken from a composition “Carmen Suite” (composed by R. Shchedrin and G. Bizet), and the used recording was from Moscow Virtuosi Chamber Orchestra with Armenian State Chamber Ensemble and Percussion Ensemble in 1984. Dance video clips were recorded beforehand specifically for the experiment in an empty room with a help of a professional dancer. The clips presented the dancer performing extracts of modern dance choreography made for the music composition “Carmen Suite”. The original choreography was by Mats Ek, but the dancer was given a freedom to perform the extracts of the choreography as her own modified solo version.

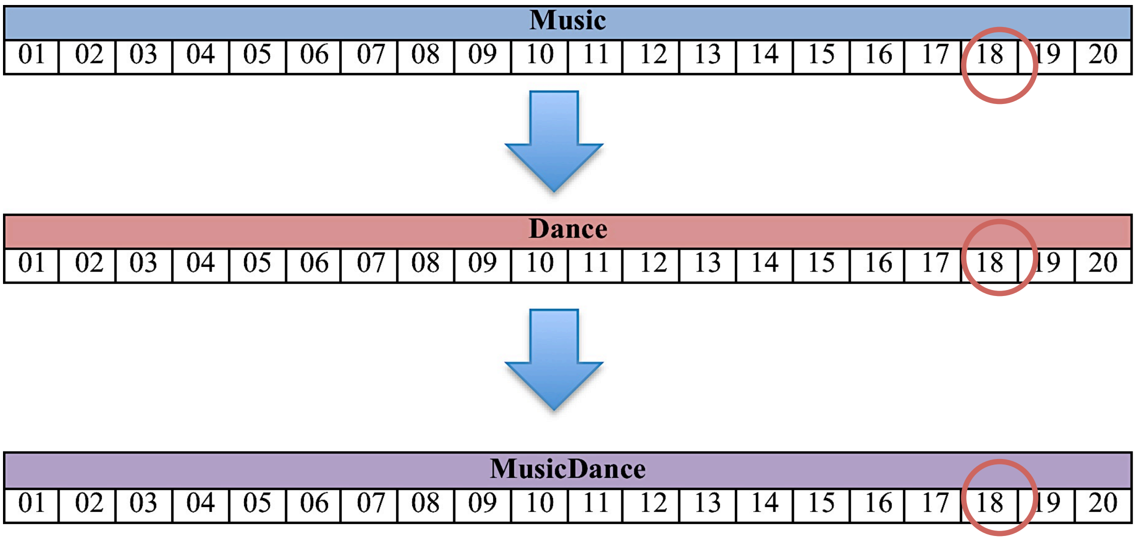


Figure 1. Stimulus presentation of the experiment. All three stimulus conditions (Music, Dance, MusicDance) were displayed for each individual subject in randomized order. Order of presented stimuli (extracts 01-20) was the same in every condition. Between every extract there was a very short pause (app. < 1 sec) in presentation, and a longer pause after every stimulus condition. EEG data collected during stimulus extract 18 in all conditions was chosen for statistical analysis.

2. 3. Equipment and the set of experiment

Electroencephalography (EEG) was recorded during the stimulus presentation. EEG was also recorded during rest, which included two rest conditions ‘Eyes Open’ and ‘Eyes Closed’ (for app. 90 seconds per each). EEG data was collected with Biosemi bioactive electrode cap containing 128 channels, which was set according to the international 10-20 –system. Sampling rate was 512 Hz, and one electrode set below the left eye served as electro-oculogram (EOG). During EEG recording subjects were sitting in a dark, electrically shielded room. Subjects were given instructions to attend to stimulus and relax, but also to avoid body movement and minimize eye blinking. Data was collected in EEG lab of Cognitive Brain Research Unit (CBRU) in the Faculty of Behavioural Science, University of Helsinki. The experiment design was planned and actualized by Hanna Poikonen (M.Sc.) as part of her doctoral studies in CBRU. The ethical board of the Faculty of Behavioural Science, University of Helsinki approved the experiment paradigm.

2. 4. Data processing

The EEG data was analyzed with MNE-Python, which is the most recent addition to the MNE software (Gramfort, Luessi, Larsson, Engemann, Strohmeier, Broadbeck, Parkkonen, & Hämäläinen, 2014). MNE-Python is an academic open-source software package for processing and visualizing M/EEG data (Gramfort, Luessi, Larsson, Engemann, Strohmeier, Broadbeck, Goj, Jas, Brooks, Parkkonen, & Hämäläinen, 2013). MNE provides a set of algorithms, from which the user can assemble complete data analysis pipelines including most phases of the M/EEG data processing. Analysis pipeline of the study presented is depicted in Figure 2.

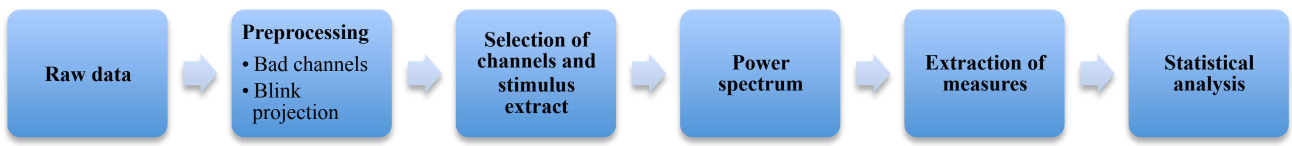


Figure 2. Analysis pipeline

MNE Python functionalities were customized to perform the steps of the data analysis. First, data was converted from Biosemi BDF file to Neuromag FIF file format, which is suitable for MNE-Python. Preprocessing, which included rejecting bad channels and removing eye blinks, was then executed for the data. Rejection of bad channels was done based on the lab logs and going through the data by eye. Eye blink artifacts were identified using the electrode placed near subjects eye, or an electrode in the head if signal showed more apparent blink artifact there. Individual blinks were then epoched and plotted one upon the other for the quality inspection. These EOG epochs were averaged for computing component vectors (PCA) that were applied using signal-space projection method (SSP). SSP method can serve as a tool to separate M/EEG data into components, and has been used to remove eye artifacts (Uusitalo & Ilmoniemi, 1997). The computed EOG SSP vectors were saved and applied to the EEG data. Average EEG was used as reference for the whole data. All steps of preprocessing were successfully made for 13 musicians (3 male and 10 female) and 15 controls (6 male and 9 female) for the data from stimulus conditions. EEG data of one female control in the two rest conditions was found not usable for analysis and was to exclude from the study. The data of this subject during stimulus conditions was still included.

Preprocessed EEG data signal from electrodes Fz, Cz and POz was chosen for further analysis. The selection of channels was made based on interest of investigating and comparing data from several brain areas. Channel Fz was selected for the investigation of electrical activity in frontal areas, channel Cz for central, and channel POz for parieto-occipital brain areas. Figure 3 shows the location of selected channels in topography of one subject. Furthermore, the selection of channels was guided by earlier presented previous research, which have measured alpha and beta oscillations from these brain areas. EEG data collected during stimulus extract number 18 was chosen for the following analysis. Duration of this extract was 64 s, which was the longest from all stimulus extracts. Music of the extract could be described intense with an accelerative feeling, but also with clear rhythm of around 110 beats per minute. Data during this extract in all stimulus conditions (Music, Dance, MusicDance) was taken to the next step of analysis (see Fig. 1).

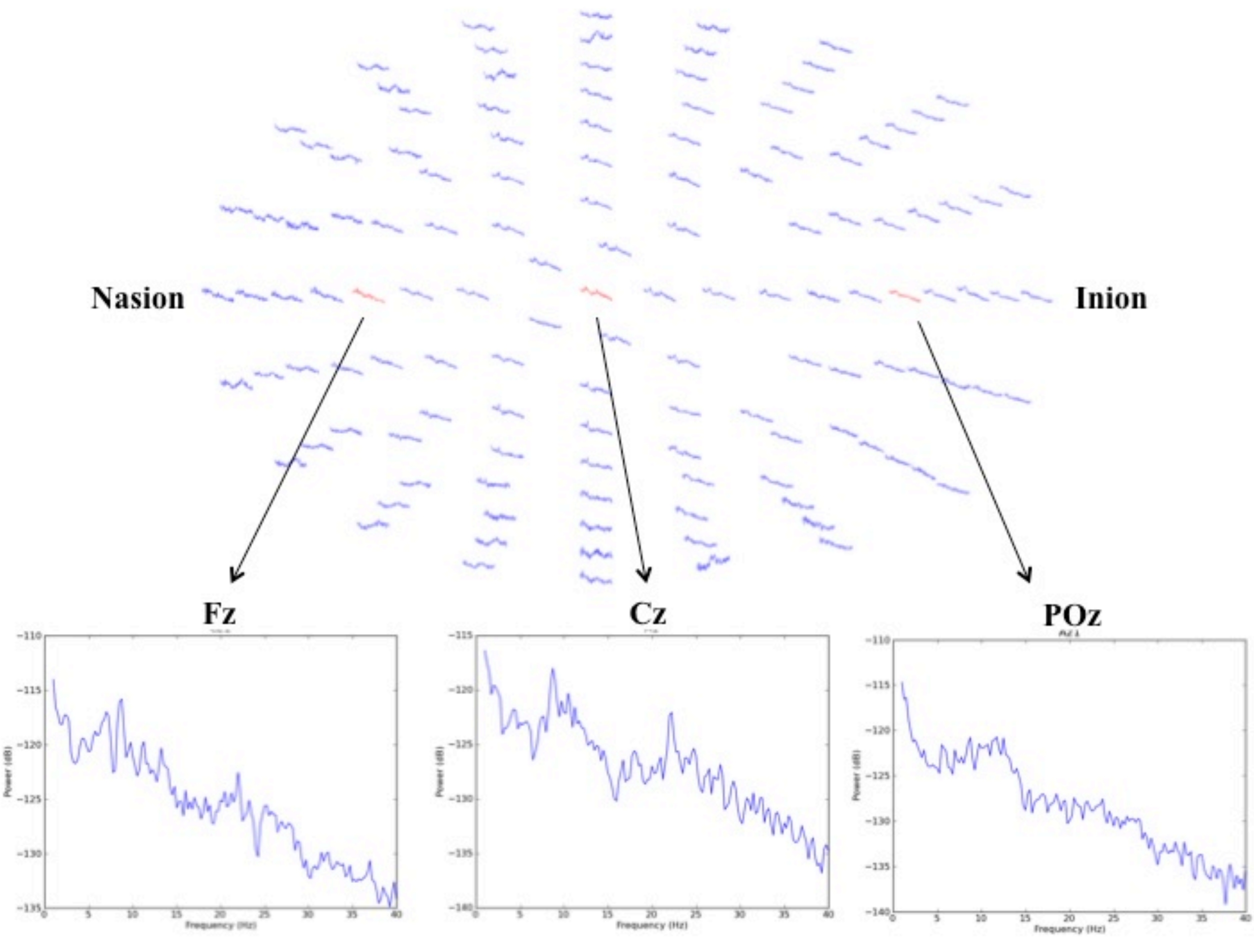


Figure 3. Power spectrum topography of one subject between 1-40 Hz during 'Music' condition. Selected channels Fz, Cz, and POz are marked in red in the topography and also shown as separate pictures below.

Power spectral density (PSD) was then calculated from EEG data to investigate the general power of oscillatory activity over the frequencies from 0 to 40 Hz. PSD describes a signal power distribution over selected bandwidth, and it is computed with widely used method of Fourier Transform. PSD was computed for the data from channels Fz, Cz, and POz in all conditions. For the two rest conditions PSD was computed for 75 sec of EEG data taken from in the middle of recording of each condition. PSD for the stimulus conditions were calculated from the EEG recording during stimulus extract 18 excluding 5 sec of data in the beginning. The distribution of power in the frequency range of 0-40 Hz in all conditions and channels for both groups is plotted in Figure 4.

Measures were extracted from PSD values separately for each condition and channel in both groups. For investigating alpha-band activity, maximum amplitude from wide range (8-15 Hz) was extracted from PSD values of every subject. Maximum amplitude was selected as a measure for alpha-band, because alpha activity can be usually seen as clear-cut peak in a power spectrum of EEG data. This was seen also in the general power spectrum of the present study depicted in Figure 4. Although alpha power peak usually centers around 10 Hz, its exact frequency varies individually. This was taken into account by selecting wide frequency range related to alpha activity. In case of beta-band activity, the rhythmic activation and its possible modulations are more widely spread over the frequency range without any apparent peak. This was also the case in this data, when the PSD pictures were observed visually (see Fig. 4). For this reason, mean amplitude was calculated from amplitude values between frequencies 17-23 Hz. The frequency range was selected based on special interest towards activation around 20 Hz.

2. 5. Statistical analysis

Statistical analysis was performed separately for three distinct data sets focusing on amplitude measures at alpha-band and beta-band range. First set included the two rest conditions collected from 13 musicians (3 male) and 14 controls (6 male). Second set consisted of data from 13 musicians (3 male) and 15 controls (6 male) in the three stimulus conditions. Third set was combined from previously mentioned sets to present all rest and stimulus conditions as an entity. Third data set was created and analyzed due to interest of comparing rest condition to stimulus conditions, and it comprised of data from 13 musicians (3 male) and 14 controls (6 male) as in the first set.

Analysis of variance (ANOVA) with repeated measures was conducted for alpha-band and beta-band data separately for all three data sets. 'Condition' and 'Channel' were set as within-subject factors, whereas 'Group' served as a between-subject factor for dividing subjects to Controls and Musicians. Pairwise comparison tests of estimated marginal means were conducted for the factors using Bonferroni adjustment. Tests of Repeated Contrasts were also performed for more specific investigation of factor effects. Mauchly's Test of Sphericity was used to test the assumption of sphericity, and a correction was made with Greenhouse-Geisser procedure in case of violated sphericity. Normality of variances was investigated with Shapiro-Wilk test of Normality and homogeneity of variances with Levene's Test, which both resulted in normality and equality in all variables of every data sets with few exceptions. The limit for statistical significance was determined as $p < .05$.

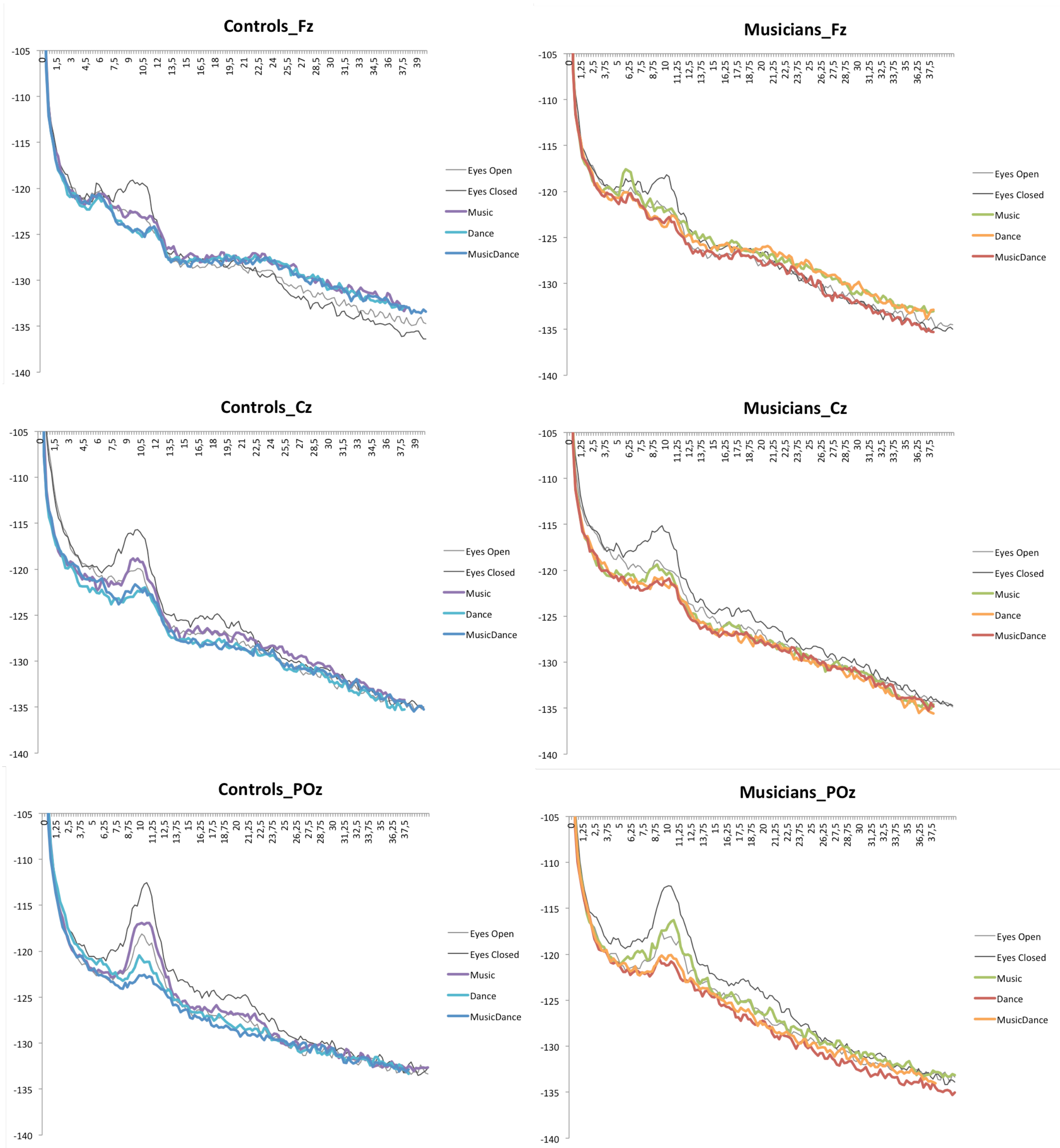


Figure 4. Power spectrum in the frequency range of 0-40 Hz. Figure shows power spectrums of both groups in every condition with separate plots for each channel. Alpha power is seen as a peak around 10 Hz.

3. RESULTS

Aim of this study was to investigate the role of musical expertise in the alpha- and beta-band activity during rest and music and dance stimulus. In addition to investigation of group differences, differences in oscillatory activity between auditory (Music), visual (Dance), audio-visual (MusicDance) and rest conditions (Eyes Open, Eyes Closed) were examined. Furthermore, the spatial occurrence of oscillation power was studied by comparing power levels from three EEG sensors located in different brain areas (Fz, Cz, POz). Results from the three data sets including rest conditions (1), stimulus conditions (2) and all conditions (3) are presented respectively for alpha- and beta-band activity. The general distributions of power in both groups during stimulus conditions are presented in Appendix I.

3. 1. Strength of alpha-band activity

3. 1. 1. Rest conditions

The ANOVA made for the rest conditions revealed no significant group differences. A significant interaction between Condition and Channel (F (2, 50) = 4.694 $p < .05$) was found. There was a significant main effect of Condition (F (1, 25) = 50.797 $p < .01$), deriving from higher power values in the condition ‘Eyes Closed’ compared to the condition ‘Eyes Open’. There was a significant main effect of Channel (F (2, 50) = 35.145 $p < .01$), which derived from growing power levels towards the occipital area, so that Fz showed the lowest and POz the highest values. Pairwise comparison of the channels unveiled a significant difference between all the channels (see Tab. 1 ‘Rest’). To investigate the found interaction between Condition and Channel (repeated) contrast tests were carried out through the data. This revealed a significant interaction between the two conditions (Eyes Open, Eyes Closed) and channels Cz and POz (F (1, 25) = 5.240 $p < .05$). This interaction seemed to rise from more steeply growing power levels from Cz to POz in condition ‘Eyes Closed’ than during condition ‘Eyes Open’.

3. 1. 2. Stimulus conditions

There was no significant difference between groups. A significant interaction of Condition and Channel was obtained (*F* (2.845, 73.967) = 7.478 $p < .01$). Also, a main effect of Condition (*F* (1.520, 39.513) = 29.486 $p < .01$) was found. Contrast test revealed that this significant effect derived from significant differences between Music vs. Dance ($p < .01$), and Music vs. MusicDance ($p < .01$). A main effect of Channel was also found (*F* (2, 52) = 14.640 $p < .01$) resulting from a significant difference between channels Fz and Cz ($p < .01$) and between Fz and POz ($p < .01$) (see Table 1), which was tested with pairwise comparison. This revealed the significant effect of Channel to stem from lower power levels in Fz compared to other channels.

Rest				Stimulus				All			
	Fz	*Cz*	*POz*		*Fz*	*Cz*	*POz*		*Fz*	*Cz*	*POz*
Fz	1	.000*	.000*	*Fz*	1	.003*	.000*	*Fz*	1	.000*	.000*
Cz	.000*	1	.006*	*Cz*	.003*	1	.112	*Cz*	.000*	1	.014*
POz	.000*	.006*	1	*POz*	.000*	.112	1	*POz*	.000*	.014*	1

*) Significant mean difference

Table 1. Significances of alpha amplitude differences between channels when compared in pairs. Results from all three data sets.

Effect of group and channel in different conditions. To understand the interaction between Condition and Channel, repeated measures ANOVA were performed separately for each condition. This revealed no significant main effect of Group for any of the conditions. Still, ANOVA for MusicDance condition unveiled a marginally significant interaction of Channel and Group (*F* (1.627) = 2.611 $p = .095$), which appeared to rise from a difference between the groups in channel POz (see Fig. 5). A significant main effect of Channel was found in Music (*F* (2, 52) = 19.693 $p < .01$) and in Dance condition (*F* (2, 52) = 4.627 $p < .05$), while in MusicDance it had an almost significant main effect (*F* (1.627, 42.314) = 3.273 $p = .057$). These differences seem to stem from respectively growing power levels from frontal (Fz) to parieto-occipital area (POz), except in the MusicDance condition, of which results are depicted in the Figure 5. Pairwise comparisons revealed significant difference ($p < .05$) between every channel in Music condition. In Dance condition only channels Fz and POz differed significantly ($p < .05$), while in MusicDance a significant difference was found only between Fz and Cz ($p < .05$). The significances from pairwise comparisons are collected in Table 2.

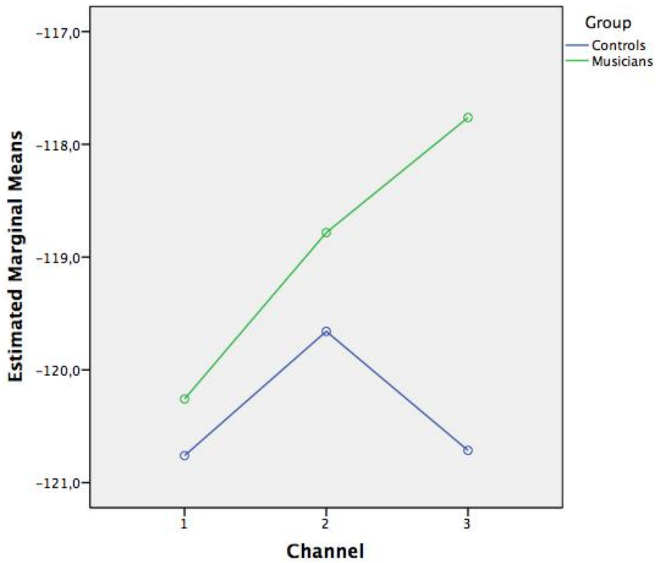


Figure 5. Alpha amplitude levels of both groups in all channels in MusicDance condition. Channels: 1= Fz, 2= Cz, 3= POz. A marginally significant interaction of Group and Channel ($p = .095$) was found in channel POz.

Music				Dance				MusicDance			
	Fz	*Cz*	*POz*		*Fz*	*Cz*	*POz*		*Fz*	*Cz*	*POz*
Fz	1	.013*	.000*	*Fz*	1	.140	.011*	*Fz*	1	.015*	.196
Cz	.013*	1	.004*	*Cz*	.140	1	1.00	*Cz*	.015*	1	1.00
POz	.000*	.004*	1	*POz*	.011*	1.00	1	*POz*	.196	1.00	1

*) Significant mean difference

Table 2. Significances of alpha amplitude differences between channels when compared in pairs. Results from analysis separately done to three stimulus conditions.

Effect of group and condition in different channels. To investigate the possible interaction of Channel and Group in MusicDance condition, repeated measures ANOVA was also conducted separately for each channel. Similar to previous results, no significant main effect of Group was found in any of the channels. All three ANOVAs revealed a significant main effect of Condition for each channel: Fz (F (2, 52) = 9.565 $p < .01$), Cz (F (1.570, 40.831) = 8.897 $p < .01$), and POz (F

(1.300, 33.793) = 36.888 $p < .01$). Pairwise comparison between conditions showed that Music condition differed significantly (p < .05) from Dance and MusicDance conditions in every channel (see Table 3). Also for the channel POz, test of contrasts resulted a significant interaction of Condition (Dance; MusicDance) and Group ($p < .05$). Controls had lower power level in POz in MusicDance condition compared to Dance condition, while in musicians the level seemed to stay the same or even grow from Dance to MusicDance condition. This significant result supports the marginally significant interaction of Channel and Group in ANOVA made separately for MusicDance condition. The results from separate ANOVAs for each channel in stimulus conditions are depicted in Appendix II.

Fz				Cz			
	Music	*Dance*	*MusicDance*		*Music*	*Dance*	*MusicDance*
Music	1	.004*	.007*	*Music*	1	.004*	.016*
Dance	.004*	1	1.000	*Dance*	.004*	1	1.000
MusicDance	.007*	1.000	1	*MusicDance*	.016*	1.000	1

POz			
	Music	*Dance*	*MusicDance*
Music	1	.000*	.000*
Dance	.000*	1	.504
MusicDance	.000*	.504	1

*) Significant mean difference

Table 3. Alpha amplitude results from pairwise comparison of stimulus conditions done separately for each channel. Music condition differed significantly from other stimulus conditions, while no significant difference was found between conditions Dance and MusicDance.

Effect of condition and channel in different groups. Because of the significant interaction between Condition and Group, the differences between conditions in POz were investigated separately in the two groups. Groups differed only in test of contrasts, which showed a significant difference between Dance and MusicDance conditions for controls ($p < .05$), but not for musicians ($p = .390$). Also, independent t-test gave an almost significant group difference in MusicDance condition in channel POz ($p = .058$). Both results indicate that musicians had tendency to higher power levels in POz during MusicDance condition compared to controls.

3. 1. 3. All conditions

ANOVA was executed also for the third data set formed from all conditions including rest and stimulus conditions. Similar to previous ANOVAs, no significant effect of Group was observed, but significant main effects for Condition (F (2.200, 55.012) = 42.260 p < .01) and Channel (F (2, 50) = 29.880 p < .01) were found. Furthermore, the same significant interaction between Condition and Channel was detected (F (5.305, 132.617) = 5.923 p < .01). Both factors were investigated with pairwise comparison. Every channel differed pairwise from each other, which is depicted in Table 1. All the five conditions were significantly different from each other (p < .01), except rest condition Eyes Open vs. Music condition, and Dance vs. MusicDance condition (see Table 4). Rest condition Eyes Closed showed the highest alpha power values. Dance and MusicDance conditions were detected to have the lowest levels of alpha power, while in Eyes Open and Music conditions the levels were discovered to be above them. All the directions of differences between conditions in all channels are displayed in Figure 6. Visual detection of power plots reveals that Music condition elicits higher alpha power in all channels and especially in POz, but this difference is not statistically significant.

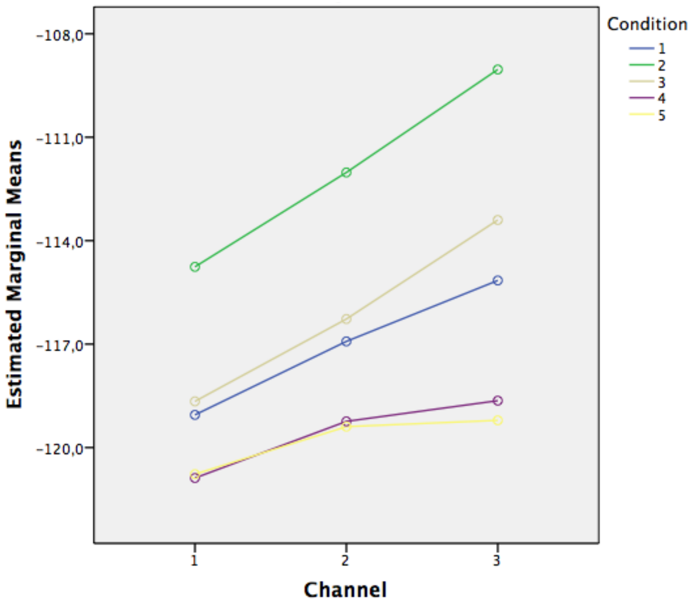


Figure 6. Alpha amplitude values in each channel in every condition. Conditions: 1= EO, 2= EC, 3= Music, 4= Dance, 5= MusicDance. Channels: 1= Fz, 2= Cz, 3= POz. Condition 'Eyes Closed' differed significantly from all the other conditions and showed the highest level of alpha power. Conditions 'Eyes Open' and Music were significantly different from other conditions except from each other. Also, conditions Dance and MusicDance had significant difference to all other conditions except when compared with each other.

All conditions					
	Eyes Open	*Eyes Closed*	*Music*	*Dance*	*MusicDance*
Eyes Open	1	.000*	.541	.007*	.009*
Eyes Closed	.000*	1	.000*	.000*	.000*
Music	.541	.000*	1	.000*	.000*
Dance	.007*	.000*	.000*	1	1.000
MusicDance	.009*	.000*	.000*	1.000	1

*) Significant mean difference

Table 4. Pairwise comparison for all conditions revealed significant differences in alpha amplitude between all the conditions, except when comparing Music with Eyes Open, and Dance with MusicDance conditions.

3. 2. Strength of beta-band activity

3. 2. 1. Rest conditions

Repeated measures ANOVA made for the two rest conditions (Eyes Open, Eyes Closed) revealed no significant group difference. A significant main effect of Condition (F (1, 25) = 33.026 $p < .01$) and Channel (F (2, 50) = 11.117 $p < .01$) and their interaction (F (2, 50) = 24.089 $p < .01$) was observed. When compared pairwise, conditions differed significantly ($p < .01$) and channel Fz differed from Cz ($p < .05$) and POz ($p < .05$). These differences seem to rise from growing levels of power from front towards the channel POz and from higher power during the condition 'Eyes Closed'. Results from rest conditions are depicted together with stimulus conditions in Figure 9.

3. 2. 2. Stimulus conditions

No significant group effect was found in stimulus conditions with repeated measures ANOVA. Only one significant main effect was detected for the factor Condition (F (2, 52) = 4.536 $p < .05$). Pairwise comparison showed that this effect resulted from significantly higher power levels for Music condition than MusicDance condition ($p < .05$). Also, factors Condition and Channel had an almost significant interaction (F (4, 104) = 2.411 p = .054). Figure 7 shows that this interaction seemed to derive from higher power in channels Cz and POz during Music condition compared to other conditions. Similar to analysis of alpha-band activity, separate ANOVAs were performed for each condition. These yield no significant differences between channels. ANOVA was then performed separately for each channel to investigate the effect of condition in different locations, and whether the found interaction between condition and channel would stem more from central or parieto-occipital channel. This revealed a significant main effect of Condition only in the channel POz (F (2, 52) = 8.779 $p < .01$). Pairwise comparison showed that this effect resulted from significantly higher power levels in Music condition compared to other conditions (Music vs. Dance: $p < .01$; Music vs. MusicDance: $p < .01$). These results are depicted in Figure 7.

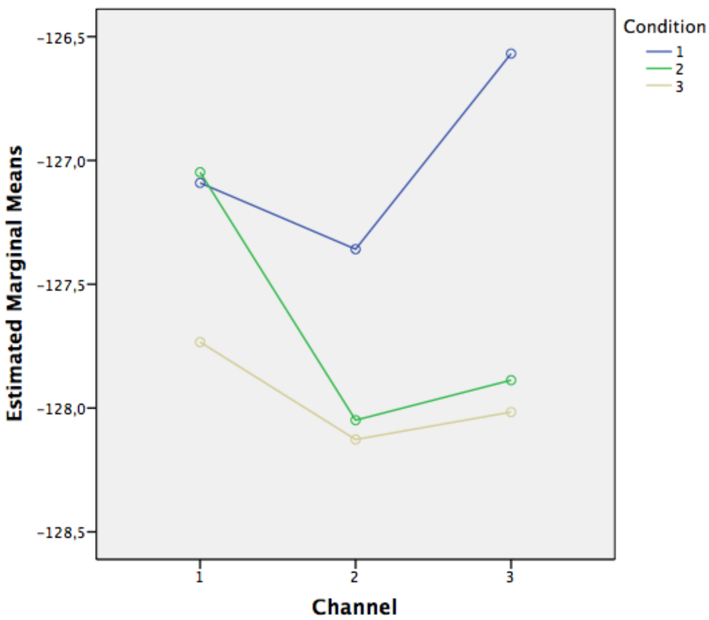


Figure 7. Beta amplitudes in different channels during stimulus conditions. Channel: 1= Fz, 2= Cz, 3= POz. Condition: 1= Music, 2= Dance, 3= MusicDance. Music condition seems to differ from other conditions in channels Cz and POz, which could explain the almost significant interaction between Condition and Channel. Statistically, Music differed significantly only from MusicDance condition.

Effect of condition and channel in different groups. ANOVA was then performed separately the two groups to the effect of condition and channel. Results of both groups did not show significant differences. Still, the power levels of the two groups seem to differ in visual detection. The results are presented in the appendix III. Interestingly, musicians show relatively apparent lower power levels in Cz in Music condition than controls when comparing the figures by eye.

3. 2. 3. All conditions

Repeated measures ANOVA for the all the conditions showed no significant group differences. Similar to stimulus data, ANOVA revealed only main effect of Condition (F (4, 100) = 9.814 p < .01). This derives from differences between the rest condition of eyes closed and all the other conditions, except when compared to Music condition. A significant interaction of Condition and Channel was also detected (F (8, 200) = 10.523 p < .01). Pairwise comparison showed significantly higher beta power in the rest condition of eyes closed than in all other conditions except when compared to Music condition. These results are depicted in Figure 9 and the pairwise comparison values are reported in table 5.

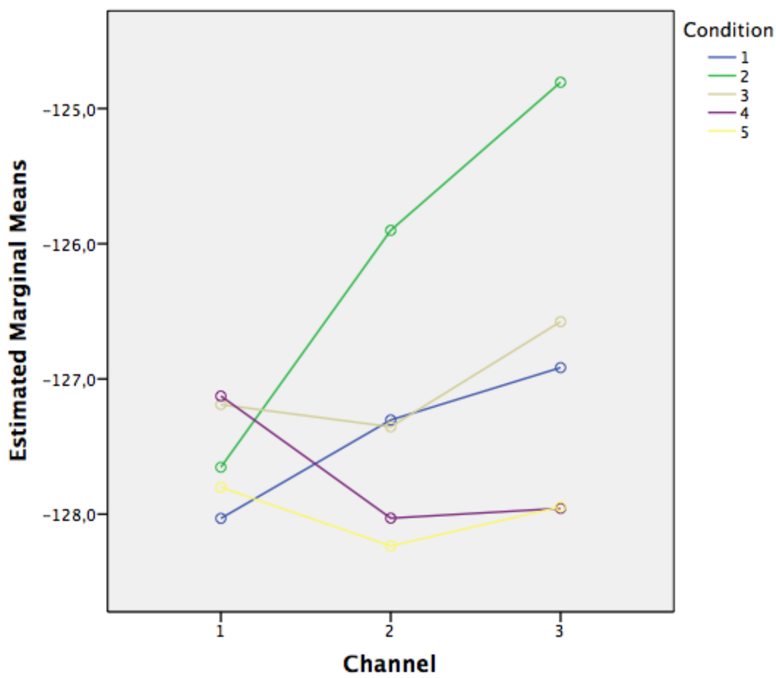


Figure 9. Beta amplitudes in channels during all the conditions. Channels: 1= Fz, 2= Cz, 3= POz. Conditions: 1= Eyes Open, 2= Eyes Closed, 3= Music, 4= Dance, 5= MusicDance. Condition Eyes Closed differs significantly from all the other conditions, except Music condition. A significant interaction of Condition and Channel seem to stem from these condition differences in channel POz.

All conditions					
	Eyes Open	*Eyes Closed*	*Music*	*Dance*	*MusicDance*
Eyes Open	1	.000*	1.000	1.000	1.000
Eyes Closed	.000*	1	.154	.002*	.000*
Music	1.000	.154	1	.883	.116
Dance	1.000	.002*	.883	1	1.000
MusicDance	1.000	.000*	.116	1.000	1

*) Significant mean difference

Table 5. Significant difference of beta amplitude across all conditions. Pairwise comparison revealed significant differences between Eyes Closed and all other conditions except Music condition.

4. DISCUSSION

The aim of the study was to investigate the activation of alpha and beta activity during music and movement perception, and the effect of musical expertise on it. The first aim was to study possible differences between musicians and non-musicians in the brain oscillatory activity underlying perception of music, dance movement, and combined music and dance. Additional attention was given to within-group effects on brain activity, including condition (rest and stimulus) and spatial (Fz, Cz, POz) factors. Professional musicians showed tendency towards higher alpha power in parietal-occipital site during audio-visual stimulation compared non-musicians. Other significant group differences were not found. Rest of the results showed quite similar modulations in alpha and beta power. When comparing conditions, alpha power was significantly higher in rest condition of eyes closed than in all other conditions. This was the same in beta power, except the rest condition of eyes closed did not differ from auditory condition. Music listening (auditory condition) enhanced significantly higher alpha and beta power than visual and audio-visual stimulus conditions. On the other hand, the alpha or beta power during music listening did not differ from rest condition of eyes open.

4. 1. Modulations in alpha-band activity

The present study results replicated the well-established facts that the alpha power in rest is highest in parietal-occipital area and grows stronger when subjects close their eyes. This posterior alpha is a classical rhythmic activity that occurs in a state of relaxed wakefulness and is most evident when eyes are closed (Niedermeyer & Lopes da Silva, 2005). The condition of eyes closed showed significantly highest alpha power compared to all other conditions. This is in line with evidence that posterior alpha is attenuated by opening the eyes and by sensory stimulation (Lopes da Silva, Gonçalves, & De Munck, 2009). In overall analysis performed for all conditions showed no significant group differences in the alpha power. This was against the expectation that alpha enhancement in frontal regions and suppression in central regions would reveal to differentiate the groups. The alpha power in auditory condition (Music) was significantly lower than in the rest condition of eyes closed, but in the same level with the rest condition when eyes were opened. Since eyes were open during all stimulus conditions, the comparison is made with the rest condition of opened eyes. Thus, the results concerning comparison of conditions showed no significant changes in alpha-band activity during music listening compared to rest. This supports the results of Wu, Zhang, Ding, Li, and Zhou (2013) that the alpha power was not significantly higher during listening of continuous music compared to silent condition. Still when results were examined visually, music listening seemed to have higher alpha power in every channel and especially in parietal-occipital channel also compared to rest condition of eyes open.

It is important to state that the present study investigated the level of general power over two frequency ranges during longer periods of stimulation. Most studies of music perception have used shorter stimulus periods for studying, for instance, short-lasting oscillatory ERS/ERD. Still, since there are only few similar studies to the present one, results are reflected to studies that are closest to compare with. Krause and co-workers have long been studying cognition-related ERS and ERD in auditory modality, and according to their conclusion the encoding of acoustic information elicits widespread alpha ERS, opposite to visual stimulation (Krause, 2006). Though natural music is a complex stimulus for auditory encoding system, this kind of significant alpha enhancement was not obtained in this study. Also, no significant group differences were found in the condition of music listening, contrary to earlier results of Hadjidimitriou, Zacharakis, Doulgeris, Panoulas, Hadjileontiadis, & Panas (2010). Group differences were not seen even when the data investigated separately for each scalp location. The result deviates from previous studies, where the location of alpha power enhancement differentiated musicians from non-musicians (Maslennikova, Varlamov, & Strelets, 2015) and professional from amateur musicians (Mikutta, Maissen, Altorfer, Strik, &

Koenig, 2014). This may derive from methodological differences at least in the case of Maslennikova et al. (2015), because their power spectral results were computed from much shorter data extract (<1 s.) just before and after music stimulus onset. Like previously stated, instead of researching this kind of immediate reaction to music stimulus, the average alpha power from the whole music extract (app. 1 min) was investigated in the present study.

In the present study, the visual and audio-visual stimulus conditions seemed to elicit quite similar reactions on the alpha activity. The only difference between these conditions was that the audio-visual condition showed tendency towards higher alpha power in parieto-occipital site in musicians compared to controls. Both visual-involved conditions displayed significantly lower alpha power in frontal, central and parietal sites compared to all the other conditions, including auditory condition and the rest condition of opened eyes. These results indicate that visual perception of movement with or without music stimulus decreases power of alpha in various brain areas. This can be partially explained with the well-known fact that alpha oscillations desynchronize in parieto-occipital areas during visual stimulation (Woertz, Pfurtscheller, Klimesch, 2004). Due to strongly correlating signal between neighbouring channels, posterior alpha may be detected also in central brain regions (Niedermeyer & Lopes De Silva, 2005).

Furthermore, decrease in alpha-band activity has been related to attentional processes, and perception of continuous movement, such as human being dancing in the stimulus of the current study, involves visuospatial attention. Though alpha activity has shown to be strongest at the parietal-occipital brain sites during spatial attention (Worden, Foxe, Wang, & Simpson, 2000; Sauseng, Klimesch, Stadler, Schabus, Doppelmayr, Hanslmayr, Gruber, & Birmauber, 2005), fronto-parietal cortex seems to be involved to visuospatial attention in a controlling role (Capotosto, Babiloni, Romani, & Corbetta 2009). Thus, the obtained decrease of alpha power in frontal and central regions during visual conditions could be related to the functioning of attentive visual system. Moreover, the results support the evidence that alpha ERD is related to motion observation (Meirovitch, Harris, Dayan, Arieli, & Flash, 2015).

Results revealed slight group difference in parieto-occipital channel in visual-involved stimulus conditions. Controls showed decrease of alpha power in parieto-occipital site in audio-visual condition compared to the condition of plain visual stimulus, while in musicians the level was statistically the same in the two conditions. Still in visual inspection, musicians seemed to have even higher alpha power in audio-visual condition compared to visual condition. This slight group difference is based on almost significant result from ANOVA, significant result from test of contrasts for separate analysis of data from parieto-occipital channel, and significantly different results from ANOVAs made separately for the two groups. All these results suggest that professional musicians show higher alpha power in parietal-occipital site during audio-visual stimulation compared non-musicians. When the brain activity of controls are assumed to represent the perceptual processing of people without any music- or dance-related expertise, in the light of results of the present study, musical expertise modifies audio-visual perception expressed by the rhythmic activity in the brain.

One possible explanation for the group difference in alpha-band power in audio-visual condition derives from the inhibitive role of alpha oscillations. Previously alpha oscillations were seen as sign of 'idling' brain state, but more recent research widely considers that the one functional role of local alpha oscillations is the inhibition of corresponding brain areas (Palva & Palva, 2007; Hummel, Andres, Altenmüller, Dichgans, & Gerloff, 2002). From this point of view, musicians may inhibit visual brain areas during audio-visual stimulation, which is seen as decreased alpha power in parieto-occipital site, due to concurrent music processing. Though the visual brain areas must be activated during visual perception also in musicians, the processing of simultaneously played music stimulus could be emphasized over their visual perceptual processes. In the cognitive level, this could be due to group differences in the allocation of attention towards audio-visual stimuli. Since decrease in power at alpha range (measured near from frontal, central, parietal and occipital midline) is considered to reflect attentional processes (Klimesch, Doppelmayr, Russegger, Pachinger, & Schwaiger, 1998), the alpha attenuation in parieto-occipital areas of controls can be interpreted as a sign of enhanced attentional processing in visual areas than in musicians. Respectively, stronger alpha power during multimodal condition of audio-visual stimulation would imply musicians to be less attended to the visual stimulus compared to non-musicians. This interpretation is based on the load theory of attention (Lavie, 1995), which claims that perception depends on the availability of limited-capacity attentional resources. When the perceptual load grows, the processing of irrelevant stimuli selectively attenuates due to limited capacity of attention. Accumulating empirical evidence supports this theory especially in visual modality, but it is still unclear whether cross-modal perceptual load will modify attentional processes (for review see Lavie, 2005), like in audio-visual condition of the current study. Also, study of underlying neural mechanisms correlated high visual perceptual load to reduced neural excitability in task-unrelated visual brain areas (Muggleton, Lamb, Walsh, & Lavie, 2008), which could be behind of the contradictory group results concerning alpha activity in parieto-occipital site in the present study. Higher alpha power in visual brain areas during audio-visual stimulation in musicians would then derive from inclined attention towards music stimulus. This allocation of attentional capabilities would result from their long-term involvement on musical experiences. Indeed, expertise has been showed to alter the effects of visual perceptual load (Green & Bavelier, 2003; Ro, Friggel, & Lavie, 2009).

On the other hand, musical expertise does not related to improved skills solely in auditory field. In fact a number of studies indicate that musical training improves variety of cognitive skills (Trainor & Corrigall, 2010), such as spatial-temporal skills (Hetland, 2000) and visual attention (Rodrigues, Loureiro, & Caramelli, 2013). Therefore, the differences in alpha power during audio-visual stimulation might result purely from advanced and more effective visual attention and not due to different usage of perceptual load capabilities. Though, if the group difference in brain activity would stem from improved visual attention capabilities of musicians, the results should have shown power differences also in the condition of plain visual stimulus. Since multisensory perception, as in the audio-visual condition of the current study, is much more than a combination of two unisensory perceptual processes, the brain activity during it is also fundamentally different (Beauchamp, 2005). Musical expertise might then be related to difference in functional neural networks used in multisensory perception. The view is supported by the brain imaging study that revealed a significant increase in grey matter volume in musicians in superior parietal region (Gaser & Schlaug, 2003), close to parieto-occipital location chosen for the present study. This region is acclaimed to play a role in the integration of multimodal sensory information (Andersen, Snyder, Bradley, & Xing, 1997), which would explain that the group differences were only detected during audio-visual but not during plain visual condition. This goes well in line with the evidence that musical expertise has modifying effects on audio-visual perception in the level of neural electrophysiology (Muscacchia, Sams, Koes, & Kraus, 2007) and brain structure (Hodges, Hairston, & Burdette, 2005).

4. 2. Modulations in beta-band activity

As in the results from alpha-band, the power of beta activity in rest was detected to rise from front towards the back of the head and had higher power in the condition of closed eyes. The rest condition of closed eyes showed significantly higher beta power than all other conditions, except auditory condition. Thus, the activity in beta-band during music listening did not significantly differ from activity in rest conditions, not even when eyes were closed. This deviates from expectations based on results of Nakamura, Sadato, Oohashi, Nishina, Futamoto, and Yonekura (1999), that music listening would increase beta power compared to rest condition of eyes open. Beta-band activity during visual conditions showed significantly lower power than auditory condition in parieto-occipital area. This is in line with the evidence that beta oscillations desynchronize during action observation in central and parietal areas (Hari, Forss, Avikainen, Kirveskari, Salenius, & Rizzolatti, 1998; Rizzolatti, Fogassi, & Gallese, 2001; Meirovitch, Harris, Dayan, Arieli, & Flash, 2015).

No significant group differences were found in beta-band power. Though visual detection revealed some beta power decrease in central channel during music listening condition only in musicians, no statistical evidence was found to these differences. Previous research imply that musicians show modified motor cortex activity during music listening compared to non-musicians (Jan-Maes, Leman, Palmer, & Wanderley, 2014; Hadjidimitriou, Zacharakis, Doulgeris, Panoulas, Hadjileontiadis, & Panas, 2010), presumably deriving from their higher level of embodiment during music-related task (Sherwin & Sajda, 2013). This led to the expectation that modulations in beta power during music listening might show group differences in central or posterior sites. Nonetheless, the results of the present study indicate that this kind of group differences is not seen in the level of oscillatory activity. More research is needed to understand the mechanisms underlying the effect of musical expertise on motor-related networks.

4. 3. Evaluation of the study and conclusions

Music enhances activity in multiple cortical areas (for a review see, Trainor & Unrau, 2012) and within specific neural networks (Alluri, Toiviainen, Jääskeläinen, Glerean, Sams, & Brattico, 2012). Nevertheless, music listening did not elicit significantly different power levels in alpha- or beta-band activity when compared to rest condition of eyes open in the present study. The present study shed light to previous contradictory results of the modulations in alpha- and beta-band activity during music listening (Petsche, Kaplan, von Stein, & Filz, 1997; Nakamura, Sadato, Oohashi, Nishina, Futamoto, & Yonekura, 1999; Wu, Zhang, Ding, Li, & Zhou, 2013). Though Nakamura et al. (1999) did find differences during music listening in the power of beta-band activity, other studies used different methods to obtain music-related changes in neural synchronization, e.g. measuring phase lag index or coherence of the neural activity. Power spectral density is assumed to measure local oscillatory activity within few centimeters, while e.g. phase synchrony provides a method to consider synchrony between two distant brain regions (Ruiz, Koelsch, & Bhattacharya, 2009). It would be interesting to study modulations in the brain activity during long music excerpts with that kind of methods measuring long-range synchronization.

Previous studies have observed that musicians have altered brain activity (Angulo-Perkins, Aubé, Peretz, Barrios, Armony, & Concha, 2014) and modulated neural networks (Jan-Maes, Leman, Palmer, & Wanderley, 2014; Chen, Penhune, & Zatorre, 2008) during music-involved tasks. Still, only group difference of marginal statistical significance was obtained in this study, which indicates that musical expertise might not have a strong effect on music perception in the level of oscillatory activity of the brain. Nevertheless, different focus of analysis might reveal more group differences in brain oscillatory activity between musicians and non-musicians not obtained in the present study. For instance, Bhattacharya, Petchse and Pereda (2001) found significant differences between musicians and non-musicians in power and long-range synchrony in gamma-band activity (>30 Hz). Thus, understanding the possible role of musical expertise to music perception and how this might be reflected as modulations of brain oscillations, requires further research with various methods.

However, results of the current study showed slight group differences in alpha-band activity during audio-visual perception. Controls showed alpha power decrease in parieto-occipital area during simultaneous music listening and dance observing, which was not seen in the group of musicians. The effect of musical expertise on audio-visual perception has been previously observed as modifications in neural activity of the brain stem (Musacchia, Sams, Skoe, & Kraus, 2007) and as differences in brain structure (Hodges, Hairston, & Burdette, 2005). The present study offers new information to this by suggesting that musical expertise also modulates the rhythmic activity of the brain in parieto-occipital site during audio-visual perception. It must be notified that this result was obtained only from one channel, and source modeling was not performed in the analysis. This sets limitations for interpretation of the results concerning the spatial source the recorded EEG data. Also, the found group difference was only marginally significant, though other significant results supported it. For these reasons, the results can be interpreted only as cues how to direct further investigations on the subject. Nonetheless, the choice of natural music and continuous dance movement as stimuli makes this study and its results unique, especially in the research domain of multisensory perception and expertise.

Musical expertise continues to be important field of study, firstly for its opportunities on gaining new knowledge about the plasticity of the brain through experience. Another equally important incitement on the matter is accumulating evidence of improved perceptual and cognitive skills correlating with musical training (Trainor & Corrigall, 2010; Herholz & Zatorre, 2012) and implications that musical experiences have positive effects on rehabilitation (e.g. Särkämö, Tervaniemi, Laitinen, Forsblom, Soinila, Mikkonen, Autti, Silvennoinen, Erkkilä, Laine, Peretz, &

Hietanen, 2008; Castro, Tillman, Luauté, Corneyllie, Dailler, André-Obadia, & Perlin, 2015). Evidently intense musical activity has powerful effects on several levels of human cognition. Like the results of the current study imply, this might include also modulations in the multimodality perception. Still, more distinct investigation of the underlying neural mechanisms lies on the shoulders of future research.

REFERENCES

Adrian, E. D. (1950). The electrical activity of the mammalian olfactory bulb. *Electroencephalography and Clinical Neurophysiology, 2*(1), 377-388.

Adrian, E. D. & Matthews, B. H. C. (1934). The interpretation of potential waves in the cortex. *Journal of Physiology, 81*(4), 440-471.

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, 59*(4), 3677-3689.

Andersen, R., Snyder, L. H., Bradley, D. C., & Xing, J. (1997). Multimodal representation of space in the posterior parietal cortex and its use in planning movements. *Annual Review of Neuroscience, 20*, 303-330.

Angulo-Perkins, A., Aubé, W., Peretz, I., Barrios, F. A., Armony, J. L., & Concha, L. (2014). Music listening engages specific cortical regions within the temporal lobes: Differences between musicians and non-musicians. *Cortex (Science Direct), 59*(1), 126-137.

Basar, E., Basar-Eroglu, C., Karakas, S., & Schürmann, M. (2001). Gamma, alpha, delta, and theta oscillations govern cognitive processes. *International Journal of Psychophysiology, 39*(2-3), 241-248.

Beauchamp, M. S. (2005). See me, hear me, touch me: Multisensory integration in lateral occipital-temporal cortex. *Current Opinion in Neurobiology, 15*(2), 145-153.

Berger, H. (1929). Über das elektrenkephalogramm des menschen. *Archiv Für Psychiatrie Und Nervenkrankheiten, 87*(1), 527-570.

Bhattacharya, J., Petsche, H., & Pereda, E. (2001). Long-range synchrony in the gamma band: Role in music perception. *Journal of Neuroscience, 21*(16), 6329-6337.

Borghi, A. M. & Cimatti, F. (2010). Embodied cognition and beyond: Acting and sensing the body.

Neuropsychologia, 48(3), 763-773.

Castro, M., Tillman, B., Luauté, J., Corneyllie, A., Dailler, F., André-Obadia, N., & Perlin, F. (2015). Boosting cognition with music in patients with disorders of consciousness. *Neurorehabilitation and Neural Repair, 29*(8), 734-742.

Engel, A. K., & Fries, P. (2010). Beta-band oscillations — signalling the status quo? *Current Opinion in Neurobiology, 20*(2), 156-165.

Gaser, C. & Schlaug, G. (2003). Brain structures differ between musicians and non-musicians. *Journal of Neuroscience, 23*, 9240-9245.

Green, C. S. & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534-537.

Hadjidimitriou, S., Zacharakis, A., Doulgeris, P., Panoulas, K., Hadjileontiadis, L., & Panas, S. (2010). Sensorimotor cortical response during motion reflecting audiovisual stimulation: Evidence from fractal EEG analysis. *Medical & Biological Engineering & Computing, 48*(6), 561-572.

Hari, R. Forss, N., Avikainen, S., Kirveskari, E., Salenius, S., & Rizzolatti, G. (1998). Activation of human primary motor cortex during action observation: A neuromagnetic study. *Proceedings of the National Academy of Sciences of the United States of America, 95*, 15061-15065.

Herholz, S. C. & Zatorre, R. J. (2012). Musical training as a framework for brain plasticity: Behavior, function, and structure. *Neuron, 76*(3), 486-502.

Hetland, L. (2000). Learning to make music enhances spatial reasoning. *Journal of Aesthetic Education, 34*(3-4), 179-238.

Hodges, D. A., Hairston, W. D., & Burdette, J. H. (2005). Aspects of multisensory perception: The integration of visual and auditory information in musical experiences. *Annals of the New York Academy of Sciences, 1060*, 175-185.

Hummel, F. Andres, F., Altenmüller, E., Dichgans, J., & Gerloff, C. (2002). Inhibitory control of acquired motor programmes in the human brain. *Brain, 125*(2), 404-420.

Janata, P., & Grafton, S. T. (2003). Swinging in the brain: Shared neural substrates for behaviors related to sequencing and music. *Nature Neuroscience, 6*(7), 682-7.

Kilner, J. M., Baker, S. N., Salenius, S., Jousmäki, V., Hari, R., Lemon, R. N. (1999). Task-dependent modulation of 15-30 hz coherence between rectified EMGs from human hand and forearm muscles. *Journal of Physiology, 516*(2), 559-570.

Klimesch, W. Doppelmayr, M., Russegger, H., Pachinger, T., & Schwaiger, J. (1998). Induced alpha band power changes in the human EEG and attention. *Neuroscience Letters, 244*(2), 73-76.

Kolb, B. & Gibb, R. (2011). Brain plasticity and behaviour in the developing brain. *Journal of the Canadian Academy of Child & Adolescent Psychiatry, 20*(4), 265-276.

Krause, C. M. (2006). Cognition- and memory-related ERD/ERS responses in the auditory stimulus modality. *Progress in Brain Research, 159*, 197-207.

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences, 9*(2), 75-82.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance, 21*(3), 451-468.

Limb, C. J. Kemeny, S., Ortigoza, E. B., Rouhani, S., & Braun, A. R. (2006). Left hemispheric lateralization of brain activity during passive rhythm perception in musicians. *Anatomical Record Part A-Discoveries in Molecular Cellular and Evolutionary, 288A*(4), 382-Discoverie.

Loomis, A. L. (1936). Electrical potentials of the human brain. *Journal of Experimental Psychology, 19*(3), 249-279.

Lopes da Silva, F. H., Gonçalves, S. I., & De Munck, J. C. (2009). Electroencephalography (EEG). In L. R. Squire (Ed.), *Encyclopedia of neuroscience* (pp. 849-855). Oxford: Academic Press.

Love S. A., Pollick, F. A., & Petrini, K. (2012). Effects of experience, training and expertise on multisensory perception: Investigating the link between brain and behavior. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 7403*, 304-320.

Luck, S. J. (2005). An introduction to event-related potential technique. Cambridge, MA: MIT Press.

Meirovitch, Y., Harris, H., Dayan, E., Arieli, A., & Flash, T. (2015). Alpha and beta band event-related desynchronization reflects kinematic regularities. *Journal of Neuroscience, 35*(4), 1627-1637.

Mikutta, C. A., Maissen, G., Altorfer, A., Strik, W., & Koenig, T. (2014). Professional musicians listen differently to music. *Neuroscience, 268*, 102-111.

Muggleton, N., Lamb, R., Walsh, V., & Lavie, N. (2008). Perceptual load modulates visual cortex excitability to magnetic stimulation. *Journal of Neurophysiology, 100*(1), 516-519.

Mulholland, T. (1995). Human EEG, behavioral stillness and biofeedback. *International Journal of Psychophysiology, 19*(3), 263-279.

Musacchia, G., Sams, M., Skoe, E., & Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences of the United States of America, 104*, 15894-15898.

Nakamura, S. (1999). Analysis of music-brain interaction with simultaneous measurement of regional cerebral blood flow and electroencephalogram beta rhythm in human subjects. *Neuroscience Letters, 275*(3), 222-226.

Niedermeyer, E., & Lopes da Silva, F. H. (2005). *Electroencephalography : Basic principles, clinical applications, and related fields* (Fifth edition. ed.).

Nunez, P. L., Wingeier, B. M., & Silberstein, R. B. (2001). Spatial-temporal structures of human alpha rhythms: Theory, microcurrent sources, multiscale measurements, and global binding of local networks. *Human Brain Mapping, 13*, 125-164.

Palva, S., & Palva, J. M. (2007). New vistas for α-frequency band oscillations. *Trends in Neurosciences, 30*(4), 150-158.

Peretz, I., & Zatorre, R. J. (2005). Brain organization for Music Processing. *Annual Review of Psychology, 56*, 89-114.

Petsche, H., Kaplan, S., von Stein, A., & Filz, O. (1997). The possible meaning of the upper and lower alpha frequency ranges for cognitive and creative tasks. *International Journal of Psychophysiology, 26*(1–3), 77-97.

Pfurtscheller, G., & Lopes da Silva, F. H. (1999). Event-related EEG/MEG synchronization and desynchronization: Basic principles. *Clinical Neurophysiology, 110*(11), 1842-1857.

Pfurtscheller, G., Stancák Jr., A., & Neuper, C. (1996). Post-movement beta synchronization. A correlate of an idling motor area? *Electroencephalography and Clinical Neurophysiology, 98*(4), 281-293.

Rau, C., Plewnia, C., Hummel, F., & Gerlof, C. (2003). Event-related desynchronization and excitability of the ipsilateral motor cortex during simple self-paced finger movements. *Clinical Neurophysiology, 114*(10), 1819-1826.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). OPINION: Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience, 2*(9), 661-670.

Ro, T., Friggel, A., & Lavie, N. (2009). Musical expertise modulates the effects of visual perceptual load. *Attention, Perception, & Psychophysics, 71*(4), 671-674.

Rodrigues, A. C., Loureiro, M. A., & Caramelli, P. (2013). Long-term musical training may improve different forms of visual attention ability. *Brain & Cognition, 82*(3), 229-235.

Ruiz, M. H., Koelsch, S., & Bhattacharya, J. (2009). Decrease in early right alpha band phase synchronization and late gamma band oscillations in processing syntax in music. *Human Brain Mapping, 30*(4), 1207-1225.

Salmelin, R., Hämäläinen, M., Kajola, M., & Hari, R. (1995). Functional segregation of movement-related rhythmic activity in the human brain. *Neuroimage, 2*(4), 237-243.

Sanes, J. N. & Donoghue, J. P. (1993). Oscillations in local-field potentials of the primate motor cortex during voluntary movement. *Proceedings of the National Academy of Sciences of the United States of America, 90*(10), 4470-4474.

Särkämö, T. Tervaniemi, M., Laitinen, S., Forsblom, A., Soinila, S., Mikkonen, M., Autti, T., Silvennoinen, H. M., Erkkilä, J., Laine, M., Peretz, I., & Hietanen, M. (2008). Music listening enhances cognitive recovery and mood after middle cerebral artery stroke. *Brain: A Journal of Neurology, 131*(3), 866-876.

Sauseng, P. Klimesch, W., Stadler, W., Schabus, M., Doppelmayr, M., Hanslmayr, S., Gruber, W. R., & Birmauber, N. (2005). A shift of visual spatial attention is selectively associated with human EEG alpha activity. *European Journal of Neuroscience, 22*(11), 2917-2926.

Schlaug, G., Jäncke, L., Huang, Y., Staiger, J. F., & Steinmetz, H. (1995). Increased corpus-callosum size in musicians. *Neuropsychologia, 33*(8), 1047-1055.

Sherwin, J. & Sajda, P. (2013). Musical experts recruit action-related neural structures in harmonic anomaly detection: Evidence for embodied cognition in expertise. *Brain & Cognition, 83*(2), 190-202.

Trainor, L. J. & Corrigall, K. (2010). Music acquisition and effects of musical experience. *Music Perception, 36*, 89-127.

Uusitalo, M. A. & Ilmoniemi, R. J. (1997). Signal-space projection method for separating MEG or EEG into components. *Medical &Amp; Biological Engineering &Amp; Computing, 35*(2), 135-140.

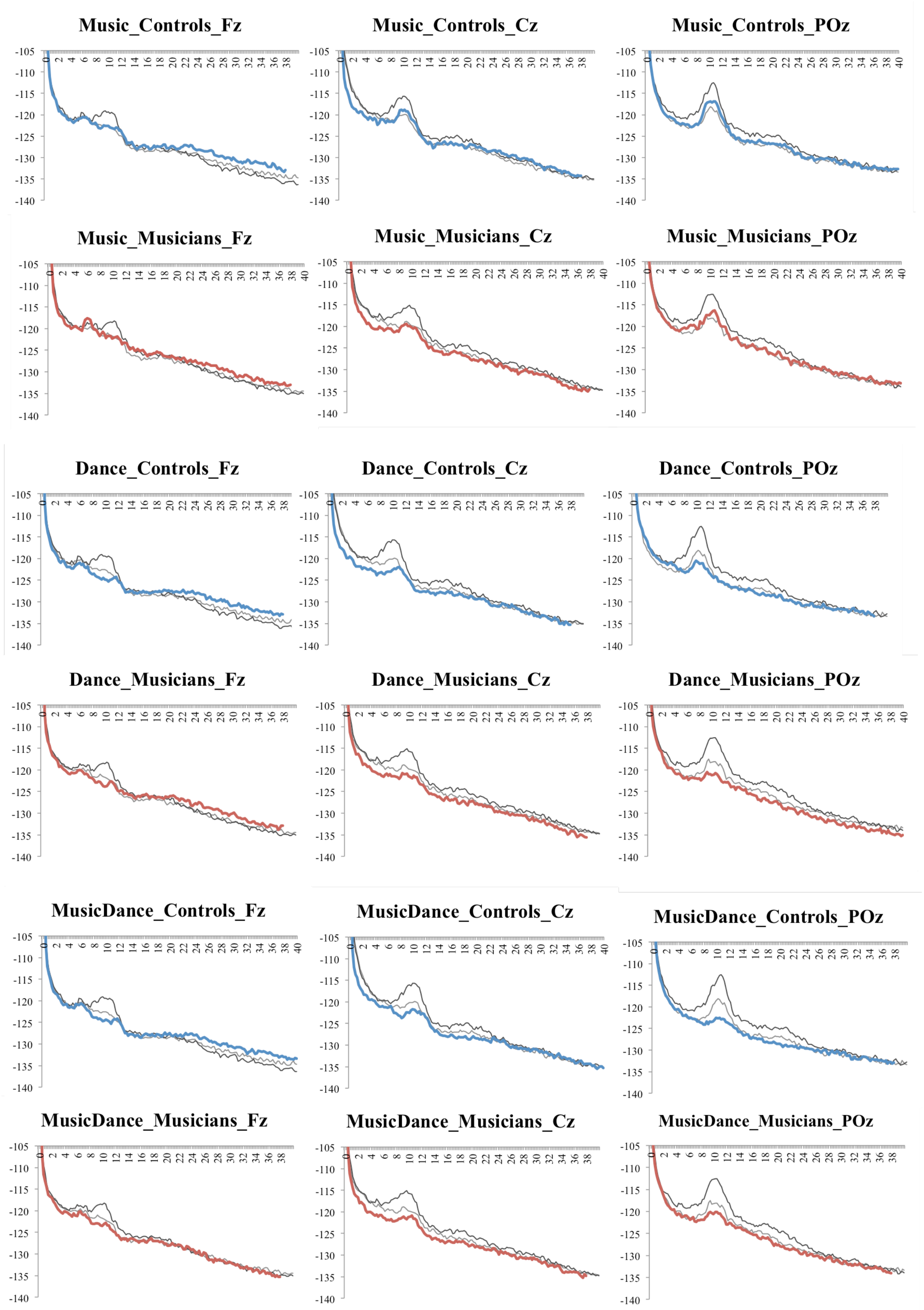
Woertz, M., Pfurtscheller, G., & Klimesch, W. (2004). Alpha power dependent light stimulation: Dynamics of event-related (de)synchronization in human electroencephalogram. *Cognitive Brain Research, 20*(2), 256-260.

Worden, M. S., Foxe, J. J., Wang, N., & Simpson, G. V. (2000). Anticipatory biasing of visuospatial attention indexed by retinotopically specific alpha-band electroencephalography increases over occipital cortex. *Journal of Neuroscience, 20*(6), RC63, 1-6.

Wu, J., Zhang, J., Ding, X., Li, R., & Zhou, C. (2013). The effects of music on brain functional networks: A network analysis. *Neuroscience, 250*, 49-59.

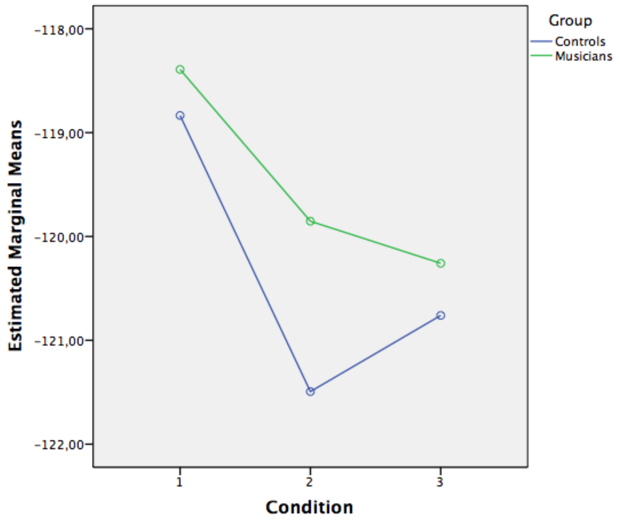
APPENDIX I

General distribution of power (0-40 Hz) presented separately in both groups and for each channel (Fz, Cz, POz) and stimulus condition (Music, Dance, MusicDance).

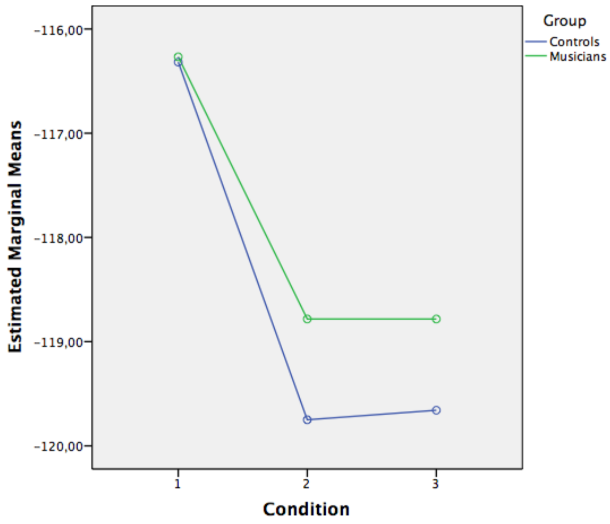


APPENDIX II

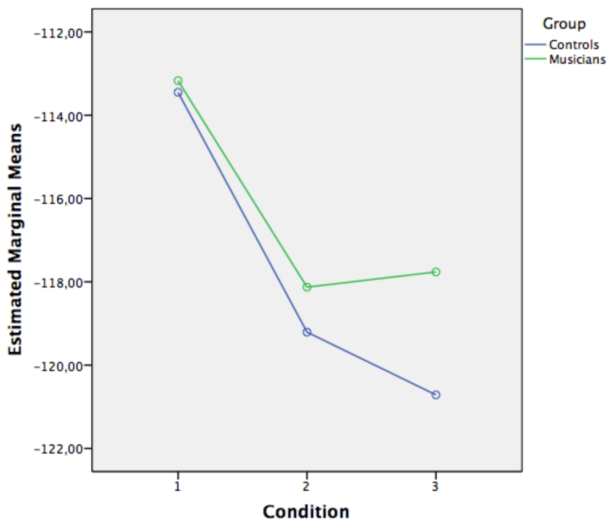
Alpha amplitudes during the three stimulus conditions (1= Music, 2= Dance, 3= MusicDance) resulted from ANOVAs performed separately for each channel. The two individual plots indicate the two groups.



Channel Fz



Channel Cz



Channel POz

APPENDIX III

Beta amplitudes in different channels (1= Fz, 2= Cz, 3= POz) during stimulus conditions (1= Music, 2= Dance, 3= MusicDance) in separate groups. Controls showed an almost significant main effect of condition, which seemed to derive from difference of Music condition compared to other conditions. In Musicians only an almost significant interaction of Condition and Channel was observed.