Task-switching, inhibition and the processing of unattended auditory stimuli in music trained and non-trained adolescents and young adults.

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Tiivistelmä – Abstrakt – Abstract

Aikaisemmissa tutkimuksissa soittoharrastus on liitetty tehostuneeseen ääniärsykkeiden prosessointiin. Tätä on mitattu muun muassa aivojen herätevasteiden (*engl.* event-related potentials, ERPs) kuten poikkeavuusnegatiivisuuden (*engl.* mismatch negativity, MMN) ja P3a:n avulla. Musiikkiharrastus on liitetty erilaisiin kognitiivisiin kykyihin. Tutkimuksen kohteena on erityisesti ollut toiminnanohjauksen rooli yhdistävänä tekijänä musiikkiharrastuksen ja kognitiivisten kykyjen välillä. Tämä tutkimus keskittyy tarkkaavaisuuden ulkopuolella tapahtuvaan äänien prosessointiin sekä siihen, miten kyseinen prosessointi liittyy kahteen toiminnanohjauksen osa-alueeseen: tehtävänvaihtoon ja inhibitioon.

Kuusikymmentäseitsemän nuorta, joista osa harrasti musiikkia (musiikkiryhmä) ja osa ei (kontrolliryhmä), jaettiin 14–16-vuotiaiden (nuorempien) ja 17–20-vuotiaiden (vanhempien) ryhmiin ja heidän suoriutumistaan tehtävänvaihto- ja inhibitiotehtävissä sekä äänissä tapahtuvien muutoksien herättämiä ERP-vasteita vertailtiin ryhmien välillä. Ääniärsykkeet koostuivat duurisoinnuista, joiden seassa esitettiin ajoittain mollisointuja.

Musiikkiryhmän MMN ja P3a vasteet poikkeaviin sointuihin olivat amplitudiltaan suurempia kuin kontrolliryhmän vasteet. Nuorempi musiikkiryhmä suoriutui inhibitiotehtävästä paremmin kuin nuorempi kontrolliryhmä, mutta tehtäväsuoriutumisessa ei ollut havaittavissa muita eroja ryhmien välillä. Mitään yhteyttä MMN:n, P3a:n ja tehtäväsuoriutumisen välillä ei ollut havaittavissa. Näin ollen tämän tutkimuksen tulokset tukevat aikaisempia löydöksiä siitä, että musiikkiharrastuksella ja ääniässä tapahtuvien muutosten hermostollisella prosessoinnilla on yhteys toisiinsa. Toiminnanohjauksen osalta tulokset olivat osittain ristiriidassa aikaisemman tutkimuksen kanssa, sillä ainoa yhteys musiikkiharrastukseen havaittiin nuoremmalla musiikkiryhmällä suhteessa kontrolliryhmään ja ainoastaan inhibitiotehtävässä.

Avainsanat – Nyckelord – Keywords
Musiikki, EEG, toiminnanohjaus, nuoret

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Previous research has linked music training to enhanced processing of unattended auditory stimuli as indexed by such auditory event-related potential (ERP) responses as mismatch negativity (MMN) and P3a. Music training has also been linked with enhanced cognitive abilities more generally, and executive functions have been proposed to mediate this link. The current study concentrates on the processing of unattended auditory stimuli and how this relates to two aspects of executive functions: task-switching and inhibition.

Sixty-seven music trained (music group) and non-trained (control group) adolescents and young adults were split into age groups, 14–16 year olds (younger) and 17–20 year olds (older), and compared in their performance on inhibition and task-switching task as well as the neural processing of unattended auditory stimuli. The ERPs were recorded in response to an oddball paradigm consisting of frequent major and infrequent minor chords.

The music group demonstrated larger MMN and P3a amplitudes than the control group during the chord paradigm. The younger music group showed better performance in an inhibition task than the younger control group. However, no other differences in task performance were found between the groups. Also, no link between MMN or P3a and task performance was found. Therefore, the results of the current study are in line with the previous findings that music training is linked to enhanced early neural processing of unattended auditory stimuli. However, the results were partly in disagreement with previous reports of enhanced executive functions in musicians as a link between executive functions and music training was only observed in the younger participants, and only in regard to the inhibition task.

Avainsanat – Nyckelord – Keywords
Music, electroencephalography, executive function, adolescents

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Foreword

The data used in this thesis was gathered as a part of a larger longitudinal study called The Early Auditory Skills Project. Most of the participants had been a part of the study since first grade, taking part in the study every two years. The study began in 2003 and is supposed to run until 2018. I had the opportunity to participate in collecting the data for the study between 2011 and 2012, and also process some of the data. The data eventually used in this thesis was, however, collected and processed by others.

I want to thank my supervisors Vesa Putkinen and Katri Saarikivi in their support and long lasting guidance during the project. I also want to thank my friends and family, who read and commented my work, and supported my writing process.

1 Introduction

The brain can be altered by our actions. Many studies have shown that training in different skills can affect the structure and functions of the brain (for a review, see: Zatorre, Fields & Johansen-Berg, 2012). Such plasticity of the brain enables us to learn new skills and adapt to changing situations. Therefore, our actions have an effect on what we can do (Stevens & Neville, 2009). One activity that has been related to changes in multiple cognitive skills is playing an instrument (for a review, see: Schellenberg & Weiss, 2013). The impact of guided or formal music training has, in particular, been the subject of numerous recent studies.

The current study investigates the link between music training, attention and executive functions by examining the neural processing of unattended auditory stimuli in an oddball paradigm, and how it relates to performance in task-switching and inhibition tasks. This study is a continuation to previous studies that were conducted on the same group of participants. The previous publications include a study by Putkinen, Tervaniemi, Saarikivi, Ojala and Huotilainen (2014) on the effects of music training on children and adolescents. They reported that music trained children and adolescents, had different event-related potential (ERP) responses to oddball auditory stimuli as recorded by electroencephalography (EEG), in comparison to non-trained children and adolescents. Furthermore, the study demonstrated that these differences accumulated with music training, pointing towards a causal link between training and augmentation of neural processing of auditory features. Another previous study investigated the connection between performance in tasks measuring executive functions, and the neural processing of auditory stimuli. The study found that executive functions modulate the maturation of early auditory processing (Saarikivi, Putkinen, Tervaniemi & Huotilainen, 2016).

1.1 EEG and ERP in oddball paradigms

EEG is a commonly used method in neuroscientific research. EEG is the measurement of the brain’s electrical activity at a given moment and it records the changes in electrical voltage over time between an electrode placed on the scalp and a reference electrode (Nobre & Silvert, 2008). The gathered data are waveforms consisting of combined intracranial signals (Luck, 2014). The method is commonly used because it is a relatively inexpensive and efficient way to safely measure brain-behaviour relations (Bell & Cuevas, 2012). Owing to its safety and non-invasiveness, EEG measurements have even been conducted on newborn babies (e.g. Hefer, Weintraub & Cohen, 2009). As well as being a method in medical research, EEG measurements are often used in behavioural research.

When compared with methods such as functional magnetic resonance imaging (fMRI) the localization of brain functions is not as precise with EEG, but what EEG loses in precision it gains in the ability to identify activity at the very moment it is happening (Rippon, 2006). Unlike fMRI, EEG can track brain events at a sub-millisecond timescale, because it measures the activation itself and not blood flow or oxygen metabolism as fMRI does (Hämäläinen & Hari, 2002). The timescale in EEG measurements is similar to that used in a magnetoencephalography (MEG). Unlike MEG, EEG equipment is usually more accessible to researchers.

In the case of research on cognition, ERP data gathered through EEG measurements are often used, especially in research related to paradigms with simple auditory or visual stimuli. An ERP measurement is, as the name suggests, the potential related to a specific event. If a research paradigm includes multiple repetitions of the stimulus of interest, an ERP can be calculated.

The raw EEG data are cut into segments around the stimulus of interest, and averaged to find the general response related to that specific event. Whereas EEG data collected during an individual measurement of a specific event consists of all the activation appearing at that moment, in averaged ERPs, activity not related to the event in question is considered to attenuate when the data are averaged together. Therefore the so-called “noise” from random activation can be removed from the data, and only the average activation related to the specific event remains (Rippon, 2006). ERP make it possible to compare brain activity related to a specific event, between groups, and with enough repetitions, even within groups.

ERPs rely on the assumption that the potential related to a specific event is time-locked to the event and always appears at the same time relative to it (Rippon, 2006). In reality, responses to anything besides direct neural stimulation can never be completely time-locked, and therefore the averaging of data can at best lead to underestimation of response amplitudes, or in the worst case, in undetectable ERPs all together (Mouraux and Iannetti, 2008). Furthermore the noise, in the measured data, can result in skewness of the average and widening of amplitude peaks, especially in later parts of the ERP curve. The problems related to ERPs could be solved by, for example, adjusting the time frames separately for each individual occurrence of the event.

Even with the critique, ERPs are still extensively measured as a part of research on cognitive processes. Since the methods have been widely used in the past, continuing to use the same methods provides a possibility to compare results with previous research. It could also be assumed that relatively automatic early onset responses, such as mismatch negativity (MMN) and P3a responses discussed further below, are less affected by timing issues than later onset components, where the amplitude and latency of the component can be more readily affected by participant dependent factors, such as attention, vigilance, and motivation.

1.1.1 MMN to stimulus changes

The MMN is an ERP component which is traditionally interpreted as the brain’s automatic response to irregularities in the auditory environment (for a review, see: Näätänen, Paavilainen, Rinne & Alho, 2007). The component can be measured with, for example, oddball paradigms, where a deviant stimulus is introduced randomly in between repeating standard stimuli. The MMN is calculated by subtracting the ERP responses to the standard stimuli from the responses to the deviant one.

In addition to being evoked by simple deviations such as changes in frequency of sinusoidal tones, MMN has been found to emerge in response to more abstract changes as well (for review, see: Paavilainen, 2013). For example, grammatical violations (Pulvermüller, Shtyrov, Hasting & Carlyon, 2008), uncommonly stressed words (Varghese, McArthur & Thompson, 2012) and even the omission of repetitive stimuli when the time between stimuli is long enough for a pattern to be recognised (Salisbury, 2012), have been found to induce MMN responses.

Many research paradigms designed to evoke an MMN are fashioned so that the participants do not pay attention to the stimuli presented, and often even concentrate on something else to occupy themselves (Näätänen et al., 2007). The rationale behind such a paradigm is that attention-dependent ERP components do not arise to overlap with the MMNs, which appear irrespective of the participants' attention.

The MMN component is negative in polarity and it usually peaks between 150 and 250 ms after the onset of a given stimulus, overlapping with the negative N1 and positive P2 components (Alho, 1995). The MMN has neural sources in the auditory cortex indicating that sequential auditory irregularities seem to be identified already at this level of the auditory system (Garza-Villarreal, Brattico, Leino, Østergaard & Vuust, 2011). The complexity of the sounds used in the experimental paradigm can, however, have an effect on where in the auditory cortex the activation takes place, and, for example, simple and complex sounds were found to elicit an MMN in partially different supratemporal neuron populations (Alho, Tervaniemi, Huotilainen, Lavikainen, Tiitinen, Ilmoniemi, Knuutila & Näätänen, 1996).

As well as the complexity of stimuli, also the type of stimuli can have an effect on the localization of an elicited MMN. Spatially distinct cortical areas seem to be specialised in phonetic and musical sounds, as shown by MMNs elicited by oddball paradigms with these types of stimuli (Tervaniemi, Kujala, Alho, Virtanen, Ilmoniemi, & Näätänen, 1998). The processing of phonetic and musical sounds, as indexed by the MMN, are lateralized in the left and right hemispheres, respectively, irrespective of the ear the sounds are played in (Tervaniemi, Medvedev, Alho, Pakhomov, Roudas, van Zuijen & Näätänen, 2000). The lateralization did not take place when only the standard or deviant sounds were used, and therefore, the lateralization can be assumed to be connected to the processing of the change in the different types of sounds.

MMN amplitude is affected by the magnitude of the change in sound, so that larger changes evoke an MMN with a larger amplitude but with decreased latency (Pakarinen, Takegata, Rinne, Huotilainen & Näätänen, 2007). Also, having a greater number of standard stimuli before the deviant stimulus can result in a larger MMN amplitude (Haenschel, Vernon, Dwivedi, Gruzelier & Baldeweg, 2005), since many deviants closer together can cause a familiarization to those stimuli.

MMN is thought to reflect the learned abilities of distinguishing between standard and deviant stimuli. For instance, Atienza, Cantero and Dominquez-Martin (2002) reported that participants could be taught to distinguish between very complex auditory patterns, and a variation in the learnt patterns would cause an MMN when listened to unattended, even 36 hours after the training. Similar effects of training have been found by a number of studies comparing the MMNs of participants with music training to those without training (e.g. Koelsch, Schröger & Tervaniemi, 1999; Fujioka, Trainor, Ross, Kakigi & Pantev, 2004; Vuust, Brattico, Seppänen, Näätänen, & Tervaniemi, 2012). For instance, Virtala, Huotilainen, Putkinen, Makkonen and Tervaniemi (2012) found that 13-year-old participants with music training presented a larger MMN amplitude to a change from major to minor chords than the same aged participants without music training. A similar effect on the MMN amplitude, combined with more accurate behavioural distinction of chords, was found with music trained adults when compared with participants without formal music training outside of that included in basic education (Virtala, Huotilainen, Partanen & Tervaniemi, 2014).

1.1.2 P3a to stimulus changes

The P3a response is related to unintentional attention-switching and is evoked by infrequent or novel stimuli (Escera, Alho, Schröger & Winkler, 2000). P3-like components have been found both in studies where the stimuli streams are attended to, as well as in ones where they are not. P3a has been evoked, for example, by using novel stimuli such as environmental sounds (Escera, Alho, Winkler & Näätänen, 1998) or task-irrelevant pictures that are shown only once, instead of repeatedly, to capture the participants attention (e.g. van Peer, Grandjean & Scherer, 2014). The P3a can also be evoked by simpler deviant stimuli among standard ones such as a minor chord in a string consisting mostly of major chords (e.g. Putkinen et al., 2014). However, Lecaignard, Bertrand, Gimenez, Mattout and Caclin (2015) found that the P3a component is larger when the deviant stimulus is more unpredictable, and not, for example, part of a pattern or repeated multiple times.

The P3a appears at the electrodes placed on the frontal and central areas of the scalp (Escera et al., 2000). It has been suggested that the component is linked to fronto-cortical dopamine and serotonin mechanisms (Heitland, Kenemans, Oosting, Baas & Böcker, 2013). Frontal lobes (Knight, 1984) and especially the hippocampus (Knight, 1996) have been identified as being crucial to the formation of the P3a. It has also been suggested that, though the hippocampus is crucial to P3a's formation, the component's appearance is linked to activity in a pathway between frontal temporal or parietal areas (Polich, 2003).

There is some controversy around the relation of the P3a response to cognitive functions, especially executive control. The discussion relates to whether a larger P3a response is related to enhanced or decreased cognitive control of attention processes. The main reason for this controversy seems to be whether the stimulus is attended to or not, and if it is unattended, whether there is something else towards which the participant directs their attention. For example, Yurgil and Golob (2013) found that higher working memory capacity was related to a decreased P3a amplitude to deviant stimuli in an oddball paradigm, when the participants were performing a task with a larger perceptual load. A less attention-demanding task was related to a larger P3a amplitude. A similar effect did not appear for the group with lower working memory capacity. A study by Combs and

Polich (2006), however, found that P3a amplitudes to distracting stimuli are larger in difficult tasks. The difference between these two paradigms is, however, that the one by Yugil and Golob used perceptual tasks while distracting with auditory stimuli, and the design by Combs and Polich examined an auditory task with auditory distracters. Therefore, people doing a listening task might not be able to block out distracting stimuli as efficiently as when doing a task related to another modality, such as vision.

Other research has found a link between skills in attention-switching and larger P3a amplitudes. For example, bilinguals who had learned a second language later were found to have a larger P3a than monolinguals or early bilinguals when listening to a non-speech auditory oddball paradigm (Ortiz-Mantilla, Choudhury, Alvarez & Benasich, 2010). It was suggested that the finding related to late-bilinguals’ heightened ability to detect different sounds, due to intentionally and actively practising a second language. Similarly, it has been found that in oddball paradigms, participants with music training show larger P3a amplitudes than non-trained children (Putkinen et al., 2014) and non-trained adults (James et al., 2012). Yet others have found no difference between the amplitudes of P3a between music trained and non-trained adults in a pitch discrimination task, but rather in the starting times of the component as well as its latency (Nikjeh, Lister & Frisch, 2008). In one study on music experts and laymen, it was found that musicians showed greater P3a amplitudes to changes of rhythm also in the bilateral supplementary motor areas, suggesting that rhythm, and variances in it, provoke action in highly trained music professionals (James, Michel, Britz, Vuilleumier & Hauert, 2012).

So, even as P3a is clearly related to unintentional attention-switching, the relationship between cognitive performance and the P3a is dependent on the task design as well as the participants' skill in a particular area. The results from different studies do support the idea that P3a is associated with top-down processes, and therefore related to executive functions, as suggested by Saarikivi and colleagues (2016). The extent to which the P3a amplitude can reflect training-related differences in executive functions still remains unclear.

1.2 Music and cognition

The link between music and cognition has been investigated for a long time, starting perhaps most notably from the study reporting the so-called Mozart effect (Rauscher, Shaw & Ky, 1993). The study linked listening to music composed by Mozart to higher scores in IQ measurements and performance in a test for abstract spatial reasoning. Later research found that the relationship between test performance and listening to music was most probably not due to the music being composed by Mozart, but rather the positive effect that listening to the music had on the participants' mood (for review, see: Schellenberg & Weiss, 2013). Since discovering a link between music and cognition, research has gone further into studying, not only the effects of music on listeners, but in particular, the effects of music training.

In their review, Schellenberg and Weiss (2013) note that music training and better performance in cognitive tests have been reported to correlate in several studies. Most of the studies that do not find this correlation are done on adults, in whom the effect seems to disappear. Therefore, it might be that music training offers an advantage by temporarily boosting the development of several cognitive functions. It has been suggested (e.g. Hannon & Trainor, 2007) that the link between music training and better performance in a wide array of cognitive tasks could be explained by improvements in executive functions such as attention and working memory. Enhancement of these functions would support performance in tasks typically used to investigate cognitive skills in studies. Eventually, perhaps, the ones who have no music training, catch up and reach a similar level in executive functions, therefore explaining the lack of difference found in adults. On the other hand, some studies have found the positive correlations, between music training and working memory, processing speed, and reasoning, to persist in adulthood, even when taking into account the effect of age, sex, time, parental education and hobbies (Nutley, Darki & Klingberg, 2014). Therefore, there is still considerable ambiguity concerning the nature and development of putative transfer effects of music training on cognition.

A common problem related to research on the effects of music training on cognitive performance is that generally high-performing children are likely to enrol in music classes and persist in taking lessons. Studies with random assignment would be needed, but are difficult to conduct in investigations of long-term effects of music training, since participants would have to take part in music lessons for years. The effect of music training on cognition may also be exaggerated by the multitude of correlational research (Schellenberg & Weiss, 2013). As an example of such a correlational research, Schellenberg (2006) found a relationship between high IQ, better school performance, and music lessons in children between 6 and 11 years of age and even found the effect of formal childhood music exposure to persist to early adulthood. However, it is possible that another mediating factor, besides music training, would explain the results. Longitudinal studies investigating the development of cognitive skills alongside accumulating music training are needed to supplement the view produced by cross-sectional studies.

Playing music is a complex task which is interrelated with higher cognitive function and it cannot be considered a completely different modality which can be separated from other aspects of cognitive performance. Therefore, it has been suggested that the question of causality between music training and high cognitive performance (Nutley et al., 2014). However, studies employing control groups that engage in activities that are as similarly complex and cognitively demanding as music training may be able to further understanding about whether music training as an activity has a special effect on the development of cognitive functions. Recently, the relationship between music training and executive functions has been of special interest in the study of transfer effects of music training. Degé, Kubicek and Schwarzer (2011) argue that the mediating factor between the correlation of intelligence and music training are in fact executive functions. Executive functions are vital for many aspects of life. Therefore, the possibility of improving children's executive functions through music training is intriguing, especially if it could be used to support those with least initial skill in their learning (for a review, see: Diamond, 2012).

1.2.1 Executive functions and music training

The definition of executive functions and the methods used for assessing those functions vary between studies. In a review, Diamond (2013) identifies different aspects of executive functions, and which methods have commonly been used to study them. According to the review, executive functions include inhibitory control, working memory, and cognitive flexibility that support higher-order mental processes such as reasoning, problem solving, and planning. Inhibitory control has been operationalised by tasks such as the Stroop task, Simon task, Flanker task and the Go/no-go task. As an example, the Stroop task consists of three parts: naming basic colours, reading the names of colours from a list, and naming the printing colour of incongruently printed names of the same colours. In the incongruent situation, the word "blue" printed in red ink would require the answer "red". Therefore, the incongruent situations requires a person to inhibit answering the colour that they see written, and instead use the colour cue to produce the correct name for the colour. Standardised by the naming and reading speed, the naming speed and accuracy in the incongruent situation is considered to reflect inhibitory control. The other tasks typically used to measure inhibitory control similarly require inhibition of prepotent or automatic responses.

Cognitive flexibility and its subcomponents, task-switching or set-shifting and fluency, have also been measured with a wide variety of tasks in research literature. Fluency tasks, task-switching or set-shifting tasks require switching between response strategies as task requirements change. A commonly used task-switching task is the Wisconsin Card Sorting Task, where participants deduce how to match cards according to certain rules and are then required to alter their responses when the rule unexpectedly changes.

Why music training would benefit executive functions can be explained by the cognitive demands of playing music. Playing a musical instrument requires continued concentration on multiple simultaneous tasks, and therefore could be considered as practice in, among others, concentration and working memory.

Contradicting results as to whether music training is associated with enhanced executive functions, have been found. Bialystok and DePape (2009) found a relationship between executive functions and music training even when the IQ of music trained and non-trained participants was similar. On the other hand, Schellenberg (2011) studying the effects of music training in 9- to 12-year-old children did not find a similar association. The results of IQ tests and different measures of executive functions showed that the music trained group performed better in IQ tests, but that there was no observable correlation between music training and performance in executive function tasks. The study suggested that children who take part in music training are generally higher performing, but the higher performance might not be due to better executive functions.

Similarly, according to a longitudinal study by Nutley and colleagues (2014), music training was found to have a positive correlation with reasoning, processing speed and working memory but not with reading comprehension. The study looked at how participants developed in different tasks through a six-year period with three measuring points, each two years apart. Participants were considered to have music training if they reported playing an instrument on at least two of the measuring points. The study found that the participants who played an instrument performed better on the tasks at all the measuring points. Therefore, it was concluded that no cause and effect relationship between the two could be confirmed in the study, even though a correlation was present.

Selective attention and inhibition were found to correlate with music training in a study by Degé, Kubicek and Schwarzer (2011). This research was conducted on a group of 9- to 12-year-old children with varying amounts of music lessons. Executive functions were measured using the NEPSY II (Korkman, Kirk, & Kemp, 2007) executive function assessments. The study found that the duration of music training (months of music lessons) correlated with executive functions, explaining 12–20% of the variance in each measure. Therefore, according to the results, it would seem that continued music training might help in developing executive functions at least at a younger age.

It has also been suggested that working memory is the executive control function that relates the most to music training. A study on music training and working memory found a correlation between music training and visual, phonological, and executive memory

(George & Coch, 2011). It was also found that the P3a response, referred to as P300 in the study, started earlier in music trained participants than others. The latency of the P3a correlated negatively with the extent of music training, so that the latency of the P3a response decreased as years of music training increased. Therefore, it was suggested that P3a could reflect the updating of working memory.

A study on improving working memory capacity through training in different skills, found that the capacity of working memory can be affected in many ways including counting in one's head (or abacus) and music training (Lee, Lu & Ko, 2007). The study found that music training was best at improving phonological storage in both adults and children whereas abacus training was associated with the capacity of visuospatial information storage. These results suggest that working memory can be affected in a domain-specific manner by tasks such as playing music. The study also suggested that, whereas the effects of abacus training could be quite well restricted to certain aspects of working memory, the effects of music training were more complex and widespread. Therefore music training could also have an effect on underlying mechanics instead of solely affecting memory capacity.

Even short-term music training has been found to improve executive functions as well as verbal performance in early childhood (Moreno, Bialystok, Barac, Schellenberg, Cepeda, Chau, 2015). In the study a 20 day music training period was found to have a positive effect on performance in a go/no-go task, considered to measure inhibitory control. Therefore, it was suggested that music training can transfer to other high-level cognitive skills at least in children. The study also suggests a causal relationship between music training and the improvement of executive functions.

Another component of executive functions, task-switching, has also been linked to music training. Moradzadeh, Blumenthal and Wiseheart (2015) found that music training was linked to more efficient task-switching. Music training can be thought to serve as practice for task-switching, as it for instance requires switching attention between the motor tasks associated with playing an instrument and reading notations from sheet music. Karbach and Kray (2009) found that task-switching could be trained, and task-switching training had a positive effect on other executive functions as well.

Other research has linked the P3a response to task-switching (Barcelo & Cooper, 2017; Saarikivi et. al. 2016; Barcelo, 2003). In the study by Saarikivi and colleagues (2016) an oddball paradigm consisting of major and minor chords was used to elicit P3a responses. The P3a amplitude was linked to music training as well as performance in a task-switching task. Participants without music training, who performed well in the task-switching task, were found to have greater P3a amplitudes in comparison to low-performing participants without music training.

Researchers seem to generally agree that music training has an effect on cognition, at least on some levels, even if the exact aspects of how and which cognitive functions are affected are still subject of debate. To understand this relationship more clearly and to identify some of the mechanics behind it, a lot of research has moved to identifying how the effects of music can be seen in brain functions, such as the MMN or P3a, and structure. Nutley, Darki and Klingberg (2014) found a difference in the grey matter volume in the temporo-occipital and insular cortex in music players and non-players. The volume of grey matter was larger in music players, which could be caused by the areas in question being related to visual pattern recognition, which is needed when reading music notes. They also reported a positive association between music training and working memory, processing speed, and reasoning, which supports the structural findings.

1.3 Purpose of the current study

The purpose of the current study is to find out (1) how music training affects the processing of unattended sounds in adolescents and young adults during an oddball task, and (2) whether this relationship is also mirrored in tasks requiring cognitive control.

The first hypothesis of the current study is that music trained adolescents will show enhanced processing of changes in unattended sounds as indexed by the MMN and the P3a responses. The MMN and P3a are measured while participants are concentrating on a movie and passively listening to an oddball paradigm consisting of chord changes between major and minor chords. The MMN component is expected to start earlier and have a larger amplitude in the music group than in the controls. The P3a component, following the

MMN, is hypothesised to have a larger amplitude for the music group. Even though the stimuli will be unattended, the participants will not be performing a complex task during the experiment to capture their attention and, therefore, the music group is assumed to be more prone to attention-switches towards musical stimuli.

Since music training has been linked to executive functions in past research, it is expected that similar results will be found in the current study. Furthermore, it is examined whether performance on a task-switching task will be reflected in the P3a (Saarikivi et al. 2016). An increase in P3a amplitude has been linked to music training and the same component is also related to attention-switching. Therefore, as efficient task-switching requires efficient attention-switching, the hypothesis is that a co-variation between performance in a task-switching task and P3a will be found, and this co-variation might be mediated by music training.

2 Method

2.1 Participants

Sixty-seven participants took part in the study. They were between the ages of 13 and 20 years either with music training or without music training, forming a music group and a control group, respectively. Data from eight participants were excluded from further analyses, due to a low number of artefact-free trials, resulting in data from 59 participants being used for the current study.

Twenty-nine of the participants (62.1 %, 18 females) belonged to the music group and had participated in music training since they were 4–7 years of age. 30 of the participants (46.7 %, 14 females) formed a control group with very limited or no music related training or hobbies, excluding listening to music and the compulsory music training included in basic education. All the participants in the control group had taken part in other supervised hobbies at some point in their youth.

The participants belonging to the music group had all attended an elementary school program which provided them with instrument lessons, choir and orchestra practice, and music theory as a part of the daily curriculum. The participants had also practised playing their chosen instruments outside of school, and most were familiar with more than one instrument. All participants in the music group played an instrument and had some formal training in both singing and playing. Also, all participants in the music group still played an instrument at the time of the measurements.

The participants were divided into two age groups. The younger group was formed from participants who were 13 to 16 years old during the study with a mean age of 15.14 years and a median of 15.15 years. The older group was formed from participants who were 17 to 20 years old during the study with a mean age of 19.28 years and a median age of 19.67 years. The demographics of the age groups, their sexes and how they were divided into music and control groups have been summarized in Table 1.

Table 1

Participant demographics

Age group (years)		Group Music	 Control	Total
13-16	Female	13	6	19
	Male	5	8	13
	Total	18	14	32
17-20	Female	7	7	14
	Male	4	9	13
	Total	11	16	27
Total	Famale	20	13	33
	Male	9	17	26
	Total	29	30	59

All the participants had taken part in a longitudinal study examining the effects of music training and had been invited to take part in previous measurements every two to three years since they began 1st grade at 7 years of age. The measurements related to this investigation were done as a part of the larger study during 2016. All the participants had taken part in most of the previous experiment cycles, and were therefore familiar with the design of this experiment. Written informed consent was given by guardians or by the participants themselves, if they were 18 years of age or older at the time of the measurements. Additionally, oral consent was obtained from participants of all ages. The participants were informed about the study, and they had a chance to quit at any time during the experiment if they wanted to. The experiment was approved by the Ethical committee of the former Institute of Behavioural Sciences, University of Helsinki, Finland.

All of the participants were native Finnish speakers from the Helsinki area. Most were from middle class and upper middle class families. None of the participants had reported medical issues or psychological disorders that could interfere with the research.

2.2 Procedure

The study consisted of cognitive testing and an EEG measurement. Each participant took part in the cognitive testing first. The EEG measurements for this study were conducted together with five other paradigms, which are not reported here. Overall, the experiment took about three hours for each participant, including the time to attach and remove the EEG electrodes and a break in between EEG measurements.

The measurement times were set up individually with each participant. The cognitive tests were performed in a quiet and separate room reserved for the experiment. The EEG measurements were conducted in a room that was electrically shielded and soundproof. The participants watched a silent but captioned movie of their choice, from a given selection, during the passive listening EEG experiments. In case the participants grew tired during the experiment, they were given a chance to take breaks and have a small snack.

2.3 Cognitive tests

The first part of the experiment for each participant involved a set of cognitive tasks from the NEPSY II (Korkman et al., 2007) and the WISC-IV (Wechsler, 2003) test batteries. The measurements were conducted by the researchers and psychology majors who were trained in using the methods. The tasks used were from a Finnish adaptation of the tests published by Hogrefe Psykologien Kustannus Oy (Helsinki, Finland; http://www.hogrefe.fi/).

The set of tests used included the Arrow and the Digit Span task from NEPSY-II, and the Block construction task and the Vocabulary task from WISC-IV. The Block construction and Vocabulary tasks were a part of the measurements to operationalise and control for the general intelligence of the participants. The Digit span task was used as a measure of working memory. The Arrow task was used to investigate task-switching skills, or cognitive flexibility, as well as inhibition skills. The Arrow task consists of 3 subtasks. The first task is to name what direction shown arrows are pointing to, namely, up or down. The second task, later referred to as the inhibition subtask, is to name the opposite direction to the one that the arrows are pointing to, and therefore inhibit answering according to the direction they see. The third task, later referred to as the task-switching subtask, is a mix of the previous two, where the colour of the arrow determines whether to name the direction of the arrow or its opposite. Specifically, a white arrow meant saying the actual direction of the arrow and a black arrow the opposite direction. The Arrow task, and especially the task-switching subtask were of primary interest in this study.

The participants' performance in the different tests was recorded as the amount of points they received in each task, marked by the grading instructions related to each one. In the case of the Arrow task, the marks were given as the amount of time it took to complete each exercise. The results were not compared to standardised data, or normalised between different age groups.

2.4 Measurements and paradigm

The EEG paradigm related to this experiment was an oddball paradigm consisting of musical chords. The standard stimulus was a major triad chord consisting of sinusoidal tones with the fundamental frequencies of 262, 330 and 392 Hz. The deviant stimulus was a minor triad chord consisting of sinusoidal tones with the fundamental frequencies of 262, 311 and 392 Hz. Therefore, the deviant chord differed from the standard one only by the frequency of the middle tone (i.e., *the third*, in musical terminology). The deviant chord differed from the standard chord by only about 6 %.

The standard chord was presented 455 times, whereas the deviant chord was presented 75 times during the experiment. Therefore, the paradigm consisted of 86 % standard and 14 % of deviant chords. The deviant chord appeared pseudo-randomly among the standard ones, so that each deviant chord was followed by at least two standard chords. The chords lasted for 125 ms each. The 125 ms included 5 ms rise and fall times. The chords were presented at a 725 ms stimulus-onset-asynchrony (SOA), which resulted in an experimental design lasting about 6.5 minutes.

The chords were played through Sony Dynamic Stereo Headphones (MDR-7506) at about 65 dB. The stimulus delivery was controlled with the Presentation 14.9 program.

The participants were instructed not to pay attention to the sounds they heard during the EEG measurements. They were also instructed to avoid extra movement, in order to minimise the amount of artefacts in the EEG data. Changing position, coughing and other movement was advised to be done between paradigms.

The EEG data was collected using a BioSemi Active Two device, using an electrode cap with 64 channels and right and left mastoids with a common reference electrode placed on the nose. The electrodes were situated according to the international 10–20 system. The recordings were done at a sampling rate of 512 Hz. Eye-movements were recorded using electro-oculogram (EOG) electrodes placed below the right eye and beside the right lateral canthus. At the beginning of the experimental procedure, the offset of each electrode was checked and, if possible, adjusted to less than 50 kΩ.

2.5 Data analysis

The EEG data were analysed using EEGLAB (14.0.0) which is an extension to Matlab. The continuous data were high-pass filtered with a 0.5 Hz cut-off. The data were then split into epochs around the standard and deviant stimuli, starting from 100 ms before the stimulus and ending at 400 ms after the stimulus. Channels with poor contact to the scalp and, therefore, having poor quality signals were identified as bad channels by visual inspection and removed. Similarly epochs with large artefacts were removed from the data after visual inspection.

The data were then run through independent component analysis (ICA). ICA makes it possible to identify eye-movement and blink-related components, so that they can be removed without having to discard all the data during such artifacts. The ICA components were visually inspected, and the eye movements and blink components were identified by their scalp distribution and time course, and were removed from the data.

The data were then filtered using a low-pass filter with cut-off of 30 Hz. Epochs with deflections exceeding ±100 µV were excluded from further analyses. Bad channels were interpolated using spherical interpolation. The data were re-referenced to the average voltage of the left and right mastoid channels. The re-referenced data were averaged for each individual separately for both the standard and the deviant chords. The ERPs for the standard chord were subtracted from the ERPs of the deviant chord. MMN and P3a components were identified from the resulting difference signals. The signals at the three middle line electrodes Fz, Cz and Pz (Figure 1) were studied more closely in order to find out how the ERPs differed at the frontal (Fz), central (Cz) and parietal (Pz) parts of the scalp.

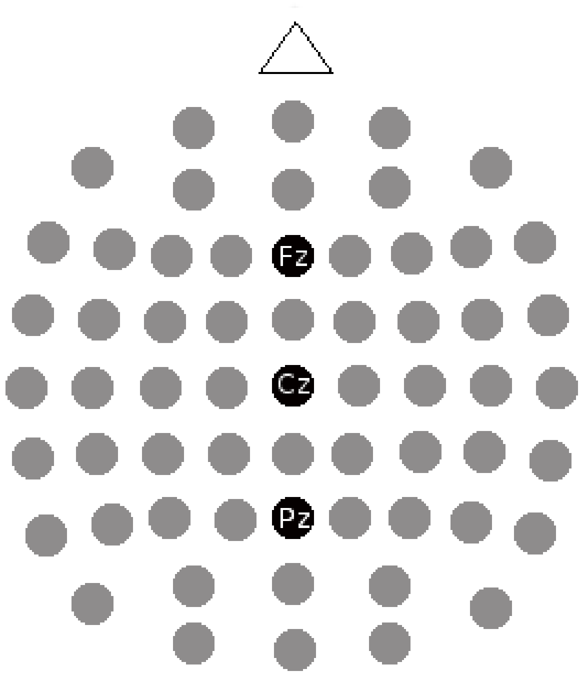

Figure 1: *Electrode positions*. The electrodes Fz, Cz and Pz and their position in reference to a head viewed from above with the nose pointing to the top.

The MMN amplitudes were calculated from the deviant-standard difference signal over a 150–200 ms time-window for the musician group and 175–225 ms for the control group. Different intervals were used because the peak of the MMN response was present earlier for the music group than for the control group. This enabled comparison between the MMN responses of different individuals. A similar analysis was done for the P3a response using the time window of 275–325 ms for both groups.

A general linear model (GLM) was used for the statistical analysis with the between-subject factors of group (music or control) and age group (younger and older) and location (frontal to posterior). The assumption of sphericity was checked using Mauchly's test, and in the cases where sphericity could not be assumed, the appropriate Greenhouse-Geisser estimates of the values were reported. In a set of additional repeated measures analysis of variances (ANOVAs), the performance in the Arrow task as indexed by completion time was included as a covariate for the inhibition and task switching subtests separately. The composite of the Z-scores for the digit span, block-design and vocabulary tasks was compared between the groups with a univariate ANOVA. Scores for the Digit span task were also compared between the groups with a univariate ANOVA. Finally, performance in the inhibition and task-switching subtests was analysed with ANOVAs with the between-subject factors of group and age group with a composite score of vocabulary and block design as covariate-of-no-interest. The data were tested for normality, homogeneity and outliers to make sure that the assumptions of the ANOVAs were met.

3 Results

Figure 2 shows the deviant-minus-standard ERPs for both the control and the music group. There was an MMN response peaking between 150–200 ms for the music group and between 175–200 ms for the control group. There was also a clear P3a response in the music group peaking at 275–325 ms. The P3a for the control group was not as clearly defined. These intervals were studied more carefully to determine whether there is a difference between the two groups.

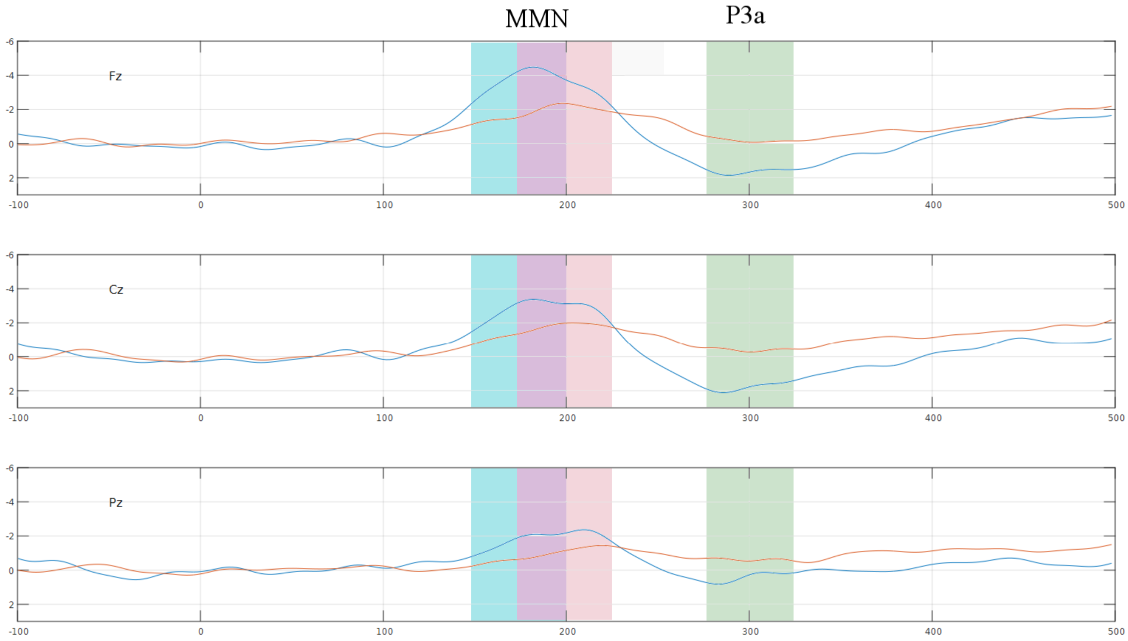

Figure 2: *Averaged MMN and P3a data.* The averaged difference between the ERPs for the standard and deviant chords from all participants. The red lines represent data from the control group and the blue lines the data from the music group. The area (150–200 ms) marked by blue and purple is the time window over which the music group's MMN amplitude (µV) was calculated. The area (175–225 ms) marked by purple and pink is the time window over which the control group's MMN amplitude (µV) was calculated. The green area (275–325 ms) represents the time window over which the P3a amplitude (µV) was calculated for each individual.

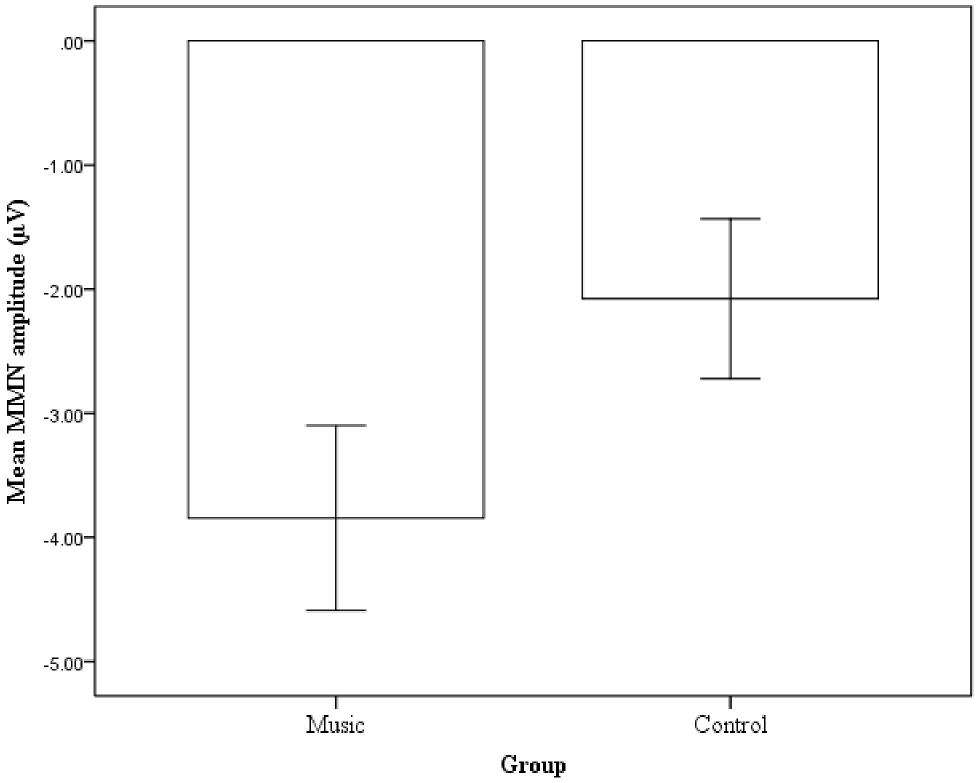

Figure 3: *Mean MMN amplitude at Fz of music and control groups.* The lines represent a confidence interval of 95 %.

3.1 MMN

Electrode location (frontal to parietal) had a significant main effect on the MMN amplitude [F(1.40, 76.76) = 31.02, $p < .001$]. There was also a significant main effect according to the group the participants belonged to [F(1, 55) = 7.56, $p < .01$] indicating that the MMN amplitude was larger in the music group than in the control group (Figure 3). The GLM results also showed a significant interaction between location and group, [F(1.40, 76.76) = 4.06, $p < .05$] indicating the magnitude of group difference varied across the channels.

A Bonferroni post-hoc comparison showed that the MMN amplitude was larger in the music group than in the control group at Fz, ($p < .001$) and at Cz ($p < .05$), but not at Pz ($p = .15$). Furthermore, the MMN responses in the music group differed from each other between each location (Fz > Cz > Pz, all $p < .001$). The control group's responses at Fz and Cz did not differ from each other ($p = .66$), but the MMN response at Pz differed from

Fz and Cz ($p < .05$, in both cases), showing that in both groups the response is stronger at the frontal channels.

No other significant main effects or interactions were found.

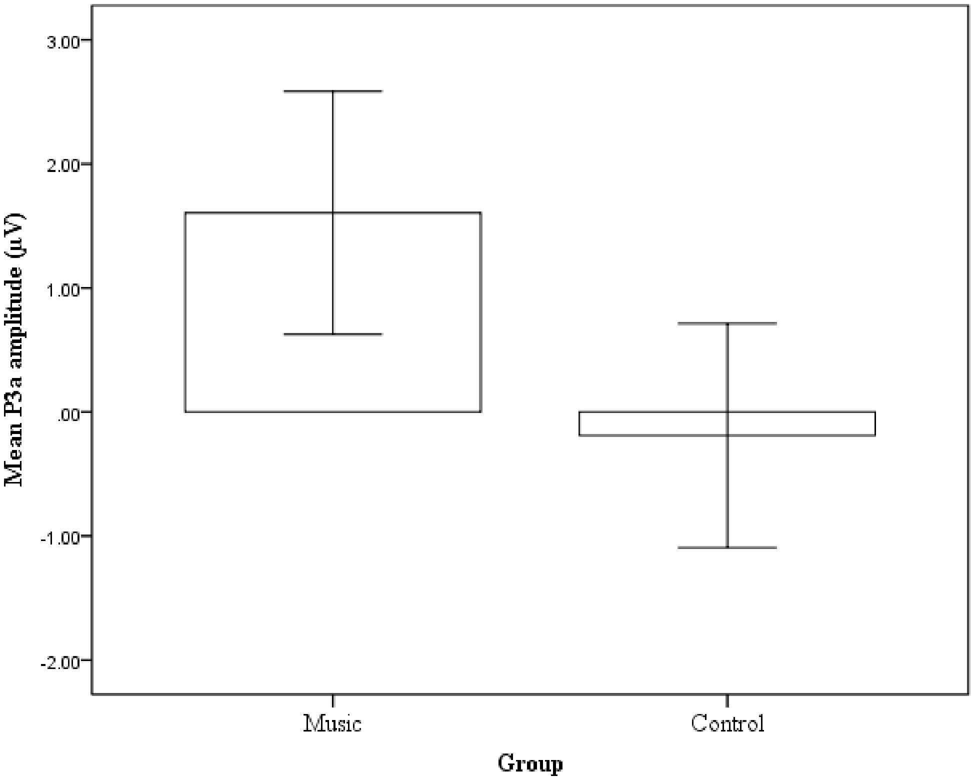

Figure 4: *Mean P3a amplitude at Fz of music and control groups.* The lines represent a confidence interval of 95 %.

3.2 P3a

The mean P3a amplitudes for the music and the control group at Fz are shown in Figure 4. For the P3a amplitude, the significant effects found were the effect of location [F(1.41, 77.35) = 7.69, $p < .05$] and interaction between location and group [F(1.41, 77.35) = 3.58, $p < .05$] A Bonferroni post-hoc comparison showed that the music group had a stronger response than the control group at Fz and Cz (both $p < .01$) but not at Pz ($p = .17$).

The P3a amplitude difference across the channels was only observable in the results of the music group. Bonferroni post-hoc comparisons showed that, for the music group, there was a stronger response at Fz and Cz than at Pz ($p < .01$, and $p < .001$, respectively). For the control group, however, there was no significant difference between the responses at any of the locations ($p > .99$, for all three locations). Therefore, a clear fronto-central response could be recorded from the music group, but not as strong of a frontal response was identified from the control group. The results from the control group were compared to zero using a t-test, and the results showed that the null-hypothesis could not be rejected for the control group and the results, especially at the frontal and central electrodes, did not differ from zero (Fz: $p = .671$, Cz: $p = .284$, Pz: $p = .073$).

3.3 Cognitive tests

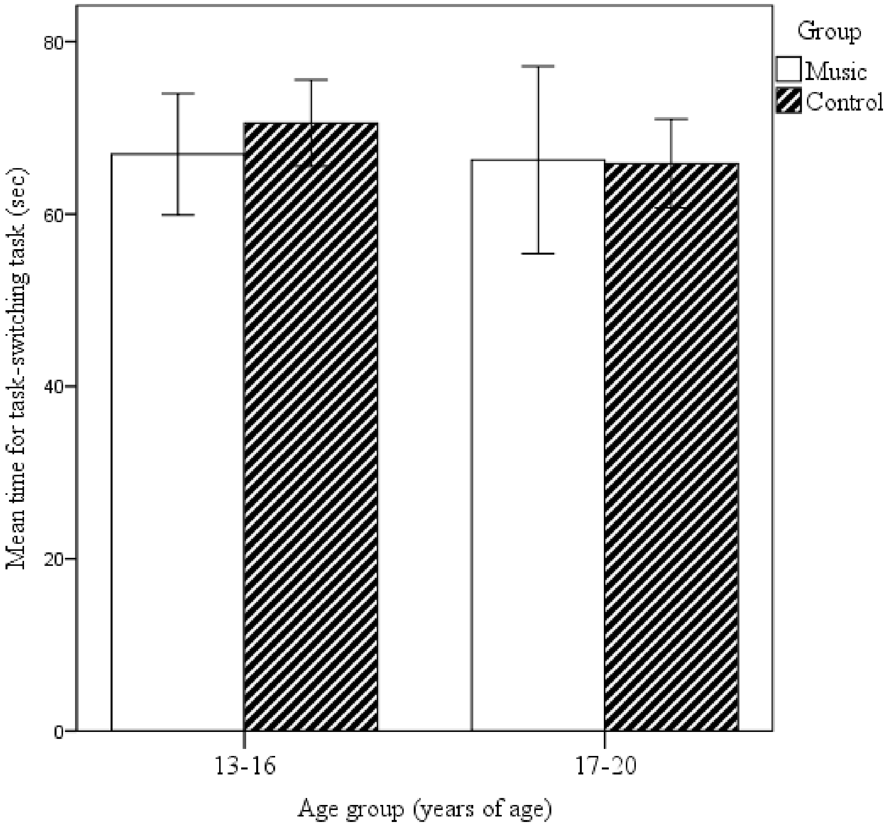

Figure 5: *Mean times for performing the task-switching subtask of music and control groups.* The lines represent a confidence interval of 95 %.

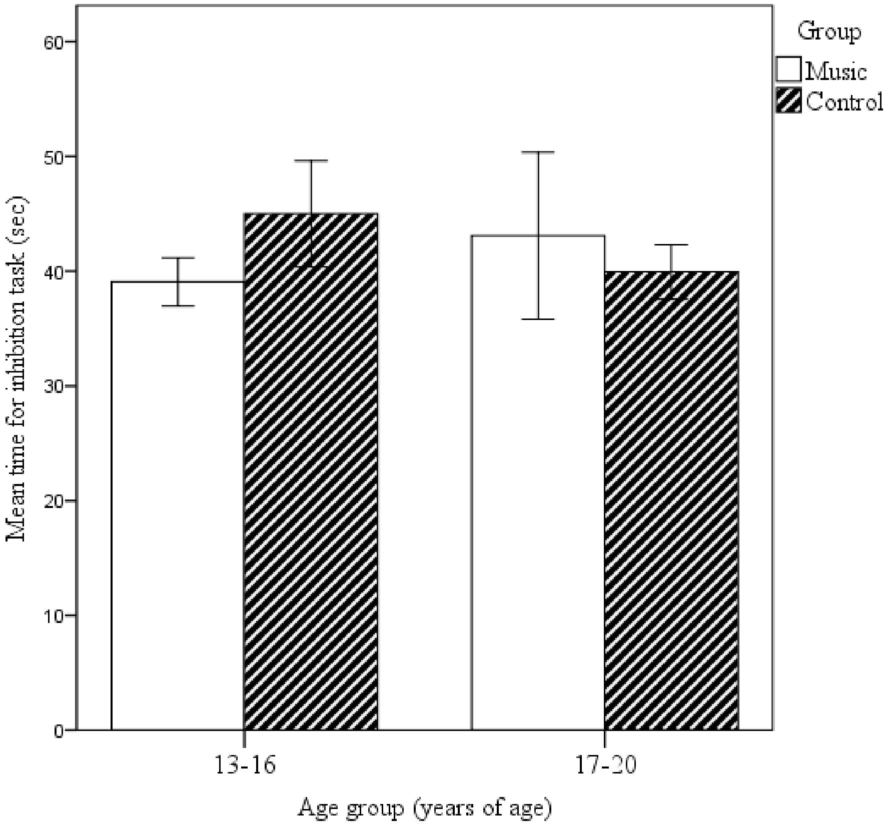

Figure 6: *Mean times for performing the inhibition subtask of music and control groups.* The lines represent a confidence interval of 95 %.

There was no significant difference between the groups in their composite score for the block-design and vocabulary tasks [F(1, 49) = 0.43, *p* = 0.84]. There was also no significant difference between the scores in the Digit span task between the music and control groups [F(1, 50) = 0.50, *p* = 0.48]. Performance in the task-switching subsection of the Arrow task did not differ significantly between the groups [F(1, 49) = 0.00, *p* = .99] or change with age [F(1, 49) = 1.24, *p* = .27] or show an interaction between age and group [F(1, 49) = 1.26, *p* = .26] even when the composite score for block-design and vocabulary tasks was taken into account. In contrast, for the inhibition subtest, there was a significant age × group interaction [F(1, 49) = 9.21, *p* < .01] when the composite score was taken into account. The post-hoc comparisons indicate that in the younger age group the music group outperformed the control group (*p* < .03) whereas in the older age group there was no significant group difference.

3.4 Relationship between MMN and P3a amplitudes, task-switching and inhibition

The GLMs, with task-switching and inhibition time as covariates, showed that the MMN and P3a mean amplitudes were not significantly related to the participants' performance in either subtask.

4 Discussion

The purpose of this research was to find out whether adolescents and young adults with a background in music training differ in their detection of deviant chords in a musical oddball paradigm, when compared to participants with limited or no music training, and how this relates to performance in task-switching and inhibition tasks. As predicted, the music group showed larger MMN and P3a amplitudes than the control group in response to deviant chords in the oddball paradigm. But, unlike predicted, the music group did not perform better in task-switching than the control group. The younger participants of the music group did, however, perform better in the inhibition task. The scores in task-switching and inhibition were not related to the MMN and P3a amplitudes even when age and group were taken into account.

4.1 MMN, P3a and the interaction with music training

The MMN results of the current study replicate the result of previous studies (e.g. Virtala et al., 2012, Putkinen et al., 2014, Saarikivi et al., 2016; Koelsch et al. 1999; Fujioka et al. 2004; Vuust et al. 2012), which have found that participants with music training have MMNs with larger amplitudes than those without music training when listening to an oddball paradigm. Therefore, the results support the assumption that music training is related to enhanced early processing of unattended auditory stimuli.

The MMN component was observed in the frontal and central electrodes, as could be expected based on previous research (Garza-Villarreal et al., 2011). As far as can be said by only comparing three centre line electrodes, the MMN was distributed slightly more frontally for the music group than for the control group, since the MMN results for the control group did not differ from each other at Fz and Cz, but did for the music group. However, a location oriented research design would be needed to conclude anything specific about the neural origin of the group difference over the frontal channels.

In the case of P3a, the amplitudes were found to be larger in the music group than in the control group when inattentively listening to an oddball paradigm consisting of chords.

The results on P3a are also in line with previous research (e.g. Putkinen et al., 2014; Saarikivi et.al., 2016) which have found unexpected unattended auditory stimuli to cause a larger amplitude P3a in music trained participants than in controls. This can, at least partially, be due to the fact that the music trained individuals are also intentionally more trained in noticing small changes in sounds.

Since P3a responses are typically observable in the frontally and centrally placed electrodes (Escera et al., 2000), the results for the control group suggest that no actual P3a was indeed measured from the control participants as a group. Whereas the results for the music group showed an observable difference between the measurements at Fz (frontal) and Cz (central) in comparison to Pz (parietal), no difference was observed in the control participants. This was supported by t-test results, which found no difference between the P3a measured in the control group and an assumed value of zero.

The non-observable P3a in the control group might be due to deviated timing in the attention-switching responses between subjects and within subjects in the control group. The deviation in timing might result in unobservable ERP components, as suggested by Mouraux and Iannetti (2008). Perhaps having less experience in separating musical chords from each other resulted in the control group's responses to be less systematic and more dependent on, for example, how much attention they were paying to the movie they were watching. Therefore, the responses might have started at different times with each presentation of the sounds resulting in unobservable P3a responses. To investigate this, individual time windows for each presented stimuli should be used, and the method of data analysis varied accordingly.

The current study demonstrates that differences in neural activity between the music and control groups are present in adolescents and young adults, not only in children. Since similar results have previously been found in the same participants when they were younger (Putkinen et al., 2014), the results of the current study suggest that there is a consistency in the MMN and P3a responses to unattended oddball stimuli. Continuing the longitudinal research would be needed in order to understand whether the effects observed stay constant throughout life, or disappear, for example, after one has stopped playing music.

4.2 Inhibition, task switching and other cognitive tests

The only differences between the control group and the music group in the cognitive tests were in their scores in the inhibition task, and that only in the younger half of the participants. As earlier research has found (Degé et al., 2011), music training seems to be linked to better inhibition. It would seem that, as others have suggested previously (Schellenberg & Weiss, 2013), the difference observed in cognitive performance between music trained and controls disappears with age, especially if the groups are of similar general intelligence.

The disappearance, of the benefits of music training, on executive functions, with age, is also supported by the fact that the difference between the music and control groups in task-switching performance, reported by Saarikivi and colleagues (2016), were not found in the current study. Even though a large part of the participants were the same in the current study as in Saarikivi and colleagues (2016), the previously found association was not observable anymore. On the other hand a recent study (Moradzadeh et al., 2015) with older participants than in the current study, did find a difference in task-switching scores between music and control groups.

In the current study, the lack of an observable difference between the control and the music groups in task-switching performance might also be due to variance in the performance between participants. Especially the variance in the older music group was large (as demonstrated by Figure 5), whereas the performance within the control group varied less. Because of the large variance, a bigger group of participants might have been needed for any effect to be observable.

The other cognitive tests used in the current design, did not result in significant differences between the control and the music groups. Therefore, it can be concluded that the general intelligence levels of the participants, regardless of group, were approximately the same. As the tests used in the current study included measures of working memory and spatial reasoning, they challenge results from other research, such as Bialystok & DePape's study (2009), which suggested that music training mediates a difference between these abilities.

It is also interesting that a difference was observed only in the inhibition task, when it could be assumed that inhibition performance should be linked to working memory, as working memory is required to actively inhibit responses. This means that the differences in inhibition, observed in the current study, are not explained by the differences in working memory.

No links between the ERP amplitude and cognitive tests performance were found. Since P3a has been linked to unintentional attention-switching (Escera et al. 2000), it was assumed to be connected to task-switching as well. Especially since Saarikivi and colleagues (2016), Barceló (2003), and Barceló and Cooper (2017) found an association between larger P3a components and task-switching ability, it could be assumed that the larger P3a components found in the current study would be connected to task-switching as well. This, however, was not the case.

No difference between the music and control groups were found in their performance on the task-switching subtask, but a difference in the P3a response was observed. Therefore, no link between P3a and task-switching was found in the current study. Although the participants watched a captioned movie while passively listening to the chord-paradigm, the amount of attention directed at the movie could not be controlled. It is possible that some individuals paid more attention to the chords than was intended, since no attention-demanding task was available. For example, instructing the participants to count the occurrence of some detail in the movie, could have assured that the participants really concentrated on what they were watching.

The larger P3a amplitude of the music group was probably more related to their familiarity with music in comparison to the control group. In other words, the chord deviation was a more salient stimulus for music trained individuals than non-trained individuals, resulting in attention capture. Due to their music training, the music group might have found the chords more important to pay attention to than the control group, since they are trained in noticing changes in musical chords. On the other hand, it is possible that the control group was able to block out musical chords more efficiently than the music group, as was supported by the unobservable P3a response in the control group. The results support the assumption that the control group might not have noticed the chord changes at all, and perhaps paid more attention to the movie than the music group.

As attention can be affected by saliency and attention to certain stimuli can be trained (Shiffrin & Schneider, 1977), it is possible that the music group was more prone to pay attention to the chords. Therefore, the P3a found could be linked to a tendency for music trained individuals to pay attention to musical chords, and not in fact reflect the participants' ability or skill in controlling their attention or differentiating between chords. A P3a elicited by saliency towards the stimulus might differ from a P3a that elicited by a change that interferes with concentration, and not be linked to task-switching in a similar manner.

4.4 Conclusions

To conclude, the current study provided support for earlier research which has related the enhanced amplitudes of MMN and P3a components to music training. It also supports the idea that cognitive control, at least in the form of inhibition, is related to music training in younger persons, but that the effect can diminish with age when persons non-trained in music catch up to a similar level of performance. The results on P3a being related to task-switching were inconclusive, perhaps because the research design did not include an attention demanding secondary task. Since the participant groups were also relatively small, and the current study might have been underpowered to identify connections between task-switching and the P3a component. More research on how different types of concentration tasks affect the processing of sound, and changes in it, could be needed. For example, is does the distraction of an auditory task affect the processing of sound differently than a visual task, and is this related to music training. A wider range of stimuli could also help in clarifying the relationship between executive control tasks such as task-switching and how it reflects to the processing of change.

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