IS NEURAL AND BEHAVIORAL SOUND PROCESSING AFFECTED BY PRACTICE STRATEGIES IN MUSICIANS?

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Abstract

Previous exploratory studies suggest that preattentive auditory processing of musicians differ depending on the strategies they use in music practicing and performance. This study aimed at systematically determining whether there are differences in neural sound processing and behavioral measures between musicians preferring and not-preferring aural strategies including improvising, playing by ear and rehearsing by listening recordings.

Participants were assigned into aural (n = 13) and non-aural (n = 11) groups according to how much they employ aural strategies, as determined by a questionnaire. The amplitude, latency, and scalp topography of the memory-related mismatch negativity (MMN) component of the event-related brain potentials were investigated with the so-called 'optimal' paradigm probing simple sound feature processing and with the 'transposed-melody' paradigm, probing complex sound pattern processing. Further, their behavioral accuracy in sound perception was tested with an attentive discrimination task in the transposed-melody paradigm and with the AMMA musicality test.

Results showed that there were group differences both at the preattentive and behavioral levels of sound processing. First, in the optimal paradigm, the MMN morphology for the isolated sound features was similar between groups but its MMN amplitude, latency and topography for different sound features differed. Second, in the 'transposed-melody' paradigm, MMN was larger for the deviant that changed its contour as compared with the deviant that changed the last tone and thus the interval between the two last tones of the melody. The Contour-MMN amplitude as determined in the beginning of the recordings correlated with the subsequent behavioral discrimination accuracy in attentive condition. However, there were no group differences in the behavioral discrimination both deviants being detected equally well. The Interval-MMN amplitudes decreased especially in the aural group after the attentive condition. Moreover, the Interval-MMN latency in the non-aural group prolonged after the attentive condition as compared to the preceding condition whereas in the aural group the MMN latency shortened. No changes were seen in the Contour-MMN between conditions with either of the groups. Third, the non-aural group outperformed the aural group in the AMMA musicality test (Tonal subtest and Total scores). Additionally, AMMA scores (especially the Rhythm) correlated significantly with the Contour-MMN amplitudes after the attentive condition.

Taken together, the present results suggest that practice strategies do not affect musicians' preattentive processing of simple sound features but might affect complex sound pattern processing. Complex sound pattern processing related also to the attentive behavioral performance in all musicians. While providing new insights into behavioral and neural differences between musicians preferring different practice strategies, results only partially support previous findings concerning discriminatory accuracy of violation within complex sound pattern learning.

Keywords: auditory sensory memory, auditory discrimination learning, practice strategies, musicians, musicality, auditory event-related potential, mismatch negativity (MMN)

Abstrakti

Aiempien tutkimusten mukaan muusikoiden käyttämät harjoittelustrategiat voivat vaikuttaa heidän esitietoiseen kuulotiedon käsittelyynsä. Tutkimuksen tavoitteena oli systemaattisesti selvittää eroaako auraalisia ja ei-auraalisia (ts. korvakuuloon perustuvia) harjoittelustrategioita suosivien muusikoiden kuulotiedon käsittely aivotutkimusten ja behavioraalisten mittausten perusteella. Auraalisilla strategioilla tarkoitettiin harjoittelukäytäntöjä, jotka sisälsivät runsaasti improvisointia, korvakuulolta soittamista ja harjoittelua äänitteiden kuuntelun avulla.

Osallistujat jaettiin auraaliseen (n=13) ja ei-auraaliseen (11) ryhmään sen perusteella kuinka paljon he kertoivat taustatietokyselylomakkeessa hyödyntävänsä auraalisia strategioita. Tutkimusmenetelminä käytettiin aivojen jännitevaste-rekisteröintejä (EEG:tä) poikkeavuusnegatiivisuusasetelmassa, AMMA-musikaalisuustestiä sekä tätä tutkimusta varten suunniteltua kyselylomaketta. EEG-kokeessa esitettiin yksinkertainen äänten piirteitä testaava optimiparadigma sekä monimutkaisten, transponoitujen, melodiakulkujen paradigma, jonka aikana testattiin myös kuulohavainnoinnin erottelutarkkuutta tarkkailutilanteessa. Erillisellä tutkimuskerralla tehtiin AMMA-musikaalisuustesti sekä täytettiin taustatietokyselylomake.

Tulosten mukaan ryhmät erosivat toisistaan sekä esitietoisella että tietoisella kuulotiedonkäsittelyn tasolla. Optimiparadigmassa MMN ei eronnut amplitudin tai latenssin osalta ryhmien välillä, mutta sen amplitudi ja jakauma eri äänen poikkeamapiirteiden välillä vaihteli. Transponoitujen melodioiden paradigmassa MMN oli vahvempi kuviopoikkeavuudelle (jossa toiseksi viimeinen sävel vaihtui) verrattuna intervallipoikkeavuudelle (jossa viimeinen sävel vaihtui). Kuviopoikkeavuuden MMN ensimmäisessä ei-tarkkailutilanteessa korreloi merkitsevästi tarkkailutilanteen behavioraaliseen erottelutarkkuuteen. Sitä vastoin, behavioraalinen erottelutarkkuus ei eronnut ryhmien välillä ja molemmat poikkeavuudet eroteltiin yhtä tarkasti. Intervalli-MMN:n amplitudi pienentyi tarkkailutilanteen erityisesti auraalisella ryhmällä. Lisäksi intervalli-MMN:n latenssi kasvoi tarkkailutilanteen jälkeen ei-auraalisella ryhmällä, kun taas auraalisella ryhmällä se pieneni verrattuna tarkkailua edeltävään tilanteeseen. Kuvio-MMN ei eronnut tilanteiden välillä kummallakaan ryhmällä. AMMA-musikaalisuustestissä ei-auraalinen ryhmä suoriutui auraalista paremmin sävelkorkeuksien erottelukykyä testaavassa (’Tonal’) osiossa ja koko testissä. Lisäksi AMMA:n tulokset (erityisesti Rytmi-osio) korreloivat merkitsevästi tarkkailutilanteen jälkeiseen kuvio-MMN:n amplitudiin.

Tulosten mukaan harjoittelustrategiat eivät näytä vaikuttavan muusikoiden esitietoiseen äänen piirteiden havaitsemiseen mutta saattavat vaikuttaa monimutkaisten melodiakulkujen havaitsemiseen. Monimutkaisten melodiakulkujen kuulotiedonkäsittely liittyi myös behavioraaliseen suoriutumiseen kaikilla muusikoilla. Tulokset tarjoavat uutta tietoa erilaisia harjoittelustrategioita suosivien muusikoiden välisistä eroista behavioraalisen ja neuraalisen tarkastelun tasoilla, mutta tukevat vain osittain aiempia aivotutkimuslöydöksiä poikkeavuuksien erottelutarkkuudesta monimutkaisten äänisarjojen oppimisen yhteydessä.

Avainsanat: sensorinen kuulomuisti, äänten erottelun oppiminen, harjoittelustrategiat, muusikot, musikaalisuus, kuuloherätevaste, poikkeavuusnegatiivisuusvaste (MMN)

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Master's thesis including neurocognitive and behavioral aspects of musical expertise felt like an ideal combination for me for several reasons. First of all, learning has been my favorite theme from the beginning of my Master of Psychology studies. I was not satisfied with the behavioral level explanations of how learning is happening, what affects it and how to improve it in practice. Neurocognitive side of the story got my full interest in the seminar of neurocognitive studying of music held by Docent Mari Tervaniemi. Also, concerning my "previous life" including technical and musical background this niche in the research world felt very natural choice. Ideas for the thesis were formulated during the summer 2004 when I was a voluntary summer trainee in the Cognitive Brain Research Unit (CBRU) laboratory. After accepted research plan, EEG recordings and behavioral measurements were done in relatively tight schedule during the autumn 2004 in the facilities and with the funding of the Cognitive Brain Research Unit (CBRU), University of Helsinki, Finland. I want to give my warmest thanks to my supervisors, Ph.D., Docent Mari Tervaniemi (Department of Psychology, University of Helsinki) and Ph.D. student, researcher Elvira Brattico (Cognitive Brain Research Unit) for ideas and comments, valuable practical advice, guidance and motivation for the work. Also I want to thank technical support in the CBRU and Tuomas Teinonen (Helsinki University of Technology) for helping to construct the stimuli files in hectic schedule. I appreciate all the comments from my friends and the opponent Inka Harpf in the student seminar. I want to send grateful greetings also to the Onnenmäki foundation for allowing me a grant with which I'm participating to scientific seminar in Leipzig concerning the neuroscience of music. Last but not least - dearest greetings to my husband, Olli, for endless encouragement ("*kaikki järjestyy!*") during the thesis work.

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Introduction

Experience and practice are major determinants in learning. Learning is seen as changes in the long-term, working and sensory memory functions and capacity. Memory systems can be categorized according to how long the information can be retained. Sensory memory can maintain information only for few seconds. Working memory is capable of processing and encoding information from sensory memory as well as retrieving the contents of the long-term memory (Ericsson & Kintsch 1999). Recent behavioral and neurocognitive studies with experts have shown repeatedly that long-term memory is modified by experience and training and is processed in parallel with working memory and sensory memory (Schröger, Tervaniemi & Huotilainen 2004). Neurocognitive studies with experts have shown that long-term memory can affect also the processing of sensory memory (e.g., Münte, Nager, Beiss, Schroeder & Altenmüller 2003). The effects of several years of practice and experience can be studied by comparing the memory performance of experts to non-experts. The effects of expertise can be seen behaviorally as larger memory capacity and faster reaction times (Ericsson & Kintsch 1999). One explanation for these results might be that experts can allocate more attention to new (but expertise-related) tasks because the prerequisite skills needed in the task are automated through experience. At the neural level learning-related changes can be seen functionally as enhanced neural processing and reorganized neural representations as well as structurally changed volumes of neurons in the specific brain regions that are needed in the field of expertise (e.g., Pantev et al. 2003). Brain's capability to change according to experience and training even in adulthood is called plasticity (Kolb & Whishaw 1998).

Neurocognitive studies of musicians vs. nonmusicians have provided evidence of cortical plasticity especially in the primary auditory cortex. Musicians can be considered as ideal models for plasticity studies (Münte, Altenmüller & Jäncke 2002): they start playing usually in the early childhood and continue to improve their skill by practicing even when they have reached a professional level. Practicing to play involves accurate processing of temporally and spectrally simple sounds as well as complex sounds or sound patterns. In addition to ear training, sensorimotor skills, learning abstract rules of musical syntax and reading musical scores belong essentially to the practice routines (e.g. Sloboda 1985). Many studies (Pantev, Roberts, Schulz, Engelien & Ross 2001, Münte et al. 2003, Brattico, Näätänen & Tervaniemi 2001) show enhanced sound processing in musicians. The current view is that this superiority is a result of long-term active and intensive training. Further evidence for this view is that musicians have facilitated sound processing particularly with temporally and spectrally more complex sounds (and thus music-related) rather than with other kind of stimuli when compared to non-musicians (e.g., Brattico et al. 2001). Enhanced processing of sounds in musicians may also affect the learning of new auditory material. Even a very brief but intensive discrimination training of simple auditory stimuli may functionally alter sound processing in non-musicians (Menning, Roberts & Pantev 2000, Brattico, Tervaniemi & Picton 2003). This means that a general learning capacity of the auditory central system in the brief and short-term time span might be the same in both musicians and non-musicians whereas the observed differences in auditory processing between groups might be caused by the contents and organization of long-term memory for sounds in musicians. In this study the effects of musicians' different practice strategies - presumably modifying their long-term memory - to the auditory sensory memory was explored.

An important question in the neurocognitive studies of expertise is the relation between behavioral performance and neural processing: which causes what? Generalizations or predictive explanations are rare in laboratory expertise studies because the conditions do not resemble the daily processing demands that experts may face and most of the imaging methods cannot be used in natural conditions. However, neurocognitive studies combined with passive imaging (when participants do not attend to the stimuli) and behavioral conditions (when participants actively attend to the sounds and perform a task related to them) have shown that there is a correspondence between preattentive neural sound processing and behavioral discrimination accuracy. For example, faster reaction times and higher hit rates in discrimination tasks including detection of pitch or duration changes (e.g. Tiitinen, May, Reinikainen & Näätänen 1994, Koelsch, Schröger & Tervaniemi 1999, Jaramillo, Paavilainen & Näätänen 2000) were found to relate to enhanced preattentive processing, as indicated by larger mismatch negativity (MMN) amplitude and/or shorter MMN peak latency in the EEG recordings. Similarly it has been found that high musicality test performance corresponded with enhanced MMN for similar kinds of stimuli as were in the musicality test (Lang et al. 1990, Tervaniemi, Ilvonen, Karma, Alho & Näätänen 1997). These results indicate also that automatic processing of sounds (and high musicality) is not restricted to musicians. The view of musicality as a useful aptitude when learning music, rather than as a learned skill, might justify the use of musicality tests in music school entry examinations for the prediction of the applicant's study success. In this study the relations between performance in the musicality test and in the attentive discrimination test with automatic sound processing were investigated. The following chapter introduces the concept of musicality, methods for assessing musicality and the corresponding brain studies.

Musicality test as a behavioral index of sound pattern processing

Musicality can be defined as a "*psychophysical property that enables one to experience and express oneself musically meaningfully*" (Otavan iso musiikkitietosanakirja 1980). Modern view of musicality takes into consideration that there are multiple aspects in musicality that can exist in various degrees between individuals. Musicality tests are typically categorized into achievement tests which measure already learned abilities and aptitude tests aiming to measure the potential music learning capabilities and to predict further success in studies. Achievement tests usually measure the expressive capabilities, such as repeating a musical piece or producing something new (Lotti 1987). Aptitude tests measure mainly perceptual discrimination skills and thus should not require any playing skills, specific music training (for example, knowledge of a particular musical genre or harmonization by chord cadences) or academic skills (abstract concepts such as directions of pitch, naming or counting), but just listening and judging the sound or sound pattern changes. Although age and practice as such do not seem to influence the musicality test performance, the effects of musical experience to particular subcomponents of musicality such as rhythm or pitch discrimination are not exclusionary. Also predictive validity of the musicality aptitude test seems be only partial (e.g., Lotti 1987) and other factors such as motivation (Maijala 2003), support (Moore, Burland & Davidson 2003) and practicing strategies may explain the further success in studying music.

In practice there is a lack of an agreed conceptual definition of musical aptitude that has led to several different kinds of tests. For example, the Seashore test (Seashore, Lewis & Saetveit 1960) assumes the musical aptitude as a low level sensory mechanism in auditory functions. Test items in the Seashore test measure the auditory accuracy and threshold of tone pairs (for example is the last tone higher or lower than the first tone). Sloboda (1985: 237) reported that the Seashore pitch test did not correlate with success in playing clarinet and trombone but mildly to playing violin. This could be explained by the fact that wind players need more sense of pitch because they have to tune the instrument themselves (see also Koelsch et al. 1999). Plasticity effects in the brain may also explain the finding that MMN amplitude to pitch changes is larger in participants who were superior in the pitch-discrimination subtest of the Seashore musicality test (Lang et al. 1990).

Musical aptitude could also be defined as an "ability to hear or perceive structures in auditory material" (Karma 1998). Karma test of Auditive Structuring measures discrimination of sound patterns. Thereby the task is to discriminate good Gestalts among Gestalt violations and changing expectations (Karma 1994). Instead of tone changes the structure is changing in the test items. For example, tones may change their order in the middle of the pattern so that when the standard pattern is C-D-E-F-C-D-E-F the deviant pattern is C-D-E-F-C-**E-D**-F. Tervaniemi et al. (1997) compared the detection of sound-order change (stimuli from Karma's test) and detection of single pitch change (rising by one quarter tone). They found that despite the same amount of training of the participants and the fact that all participants preattentively discriminated sound-pattern changes, there was correspondence between Karma test of Auditive Structuring scores and MMN amplitude: those participants who were superior in the Karma test had larger MMN amplitude to sound-order change than the participants who had the weakest test performance. Groups did not differ by the MMN amplitude in a pitch change condition.

It has been suggested that there should be separate tests for developmental and stabilized musical aptitude. For example, Gordon (1989) sees the stabilized musical aptitude as "audiation" that does not mean discriminating isolated sound features, imitating or memorizing the melody (as in the developmental stage) but an "*ability to hear and to comprehend music for which the sound is no longer, or may never have been, physically present"*. Whereas imitation requires the processing of "sameness", the audiation requires processing of "difference" in the auditory material. Thus, audiation reminds of the concept of well developed and accurate mental imagery. According to the idea of audiation, an Advanced measurement of Audiation (AMMA) has been developed to measure stabilized musical aptitude. AMMA tasks measure the skill of assessing whether two short melodies are exactly the same or different. If the melodies are different the participants have to decide whether the difference is rhythmic or tonal (that is pitch change). Items in the AMMA test have both rhythm and tonal features in the same melody, the melodies are longer and more complex as compared to developmental tests that have either pure rhythm tasks (with only one pitch presented) or pure melody tasks (presented without any rhythmic patterns). The relation between audiation and brain activity in musicians has been studied in an EEG study (Altenmüller & Gruhn 1997). Musicians heard a short melody at first after which they had to build a retrograde of the just listened melody in their mind (the audiation phase). After the audiation phase participants heard a comparison melody of which they had to judge whether it was a correct reversal or not. It was found that the auditory association cortex that is often related to auditory memory retrieval and processing of complex auditory patterns was activated bilaterally during the audiation task. Unexpectedly, the number of correctly solved in the audiation tasks and AMMA test scores did not correlate significantly. The reason for this result might be that the audiation task used in the EEG study did not correspond to the tasks in the AMMA test. Another brain study using the AMMA test indicated the correlation between AMMA tonal raw score and neuronal density of the primary auditory cortex (Schneider et al. 2002).

In summary, musicality can be seen as simple auditory and abstract pattern discrimination ability involving both sensory and cognitive components. However, it is not known which part of the musicality remains stable from the childhood to adulthood and which parts are developing through experience.

EEG method in the neurocognitive studies of music

The bases for neurocognitive studies of music perception are found in the brain studies of basic auditory functions, neuroanatomic foundations of the hearing mechanism and psychometric studies in music psychology. Brain studies have helped to find out how the brain processes music temporally, what subprocesses it includes, what is handled serially and what is processed in parallel (Huotilainen & Tervaniemi 2003). Neurocognitive study setting may include a combination of psychometric tasks and one or several brain imaging methods (for a review in methods, Tervaniemi & Huotilainen (submitted) and Hall, Hart & Johnsrude 2003). Correlation between neural processing and behavioral data may serve, for example, for discriminating between different subject groups.

Brain imaging methods vary according to their spatial and temporal resolution. Electroencephalogram (EEG) has been widely employed in studying music perception. EEG has poor spatial resolution (< 1 cm) but good temporal resolution (< 1 ms). Accurate temporal resolution is a necessity in studying music as it changes rapidly in time. Although EEG has not an optimal spatial resolution in revealing the origin of the electric field, the values recorded from different electrodes can be used to approximate the activation dominances across the scalp as well as differentiate between event-related potential (ERP) components at the corresponding latency ranges. EEG records the weak electricity over the scalp generated by neural activity, specifically the post-synaptic activity of pyramidal dendrites. Neural nets are activated in synchronous manner to specific events. This synchronicity permits to extract the meaningful activation information from the EEG recordings.

When the research interest is in an electrical brain response to a specified event (signal), the researcher needs to separate such brain responses to the stimulus from the ongoing brain background activity (noise). In this case, the specified event stimulus has to be repeated several hundreds times in order to extract the signal from the overall “noise” and get an average response to the specific events (the brain response is, then, time-locked to the stimulus event). This is why averaged brain waveforms for specified stimuli events are called event-related potentials (ERPs). One time window for the event is called as an epoch. Epoch usually starts 100 ms before the stimulus (or ‘event’) onset. The duration of the epoch depends on the stimulus duration and the theoretical interests of the researcher. A common procedure in the ERP data analysis is to compare averaged waveforms from the standard or baseline situation where no experimental manipulation is given to the deviant situation when some manipulation is given. Another way is to produce subtraction (or difference) waveforms where standard waveform is subtracted from the deviant waveform. This enables one to compare the difference in responses between deviant event and standard event and the effect strength between deviant events in case of multiple deviants. The following chapter introduces the key concepts, methods and findings in the field of neurocognitive studies of music perception.

Music-relevant event-related potentials (ERPs)

ERPs to auditory stimuli can be separated by their polarity (whether it is positive or negative), latency (in milliseconds), distribution across the scalp, and sensitivity to characteristic experimental manipulations (Coles & Rugg 1995). Sensitivity is seen as amplitude values in microvolts. According to latency, auditory ERPs can be categorized into early brain-stem responses, the midlatency components, the endogenous (including P1, N1, P2) and exogenous (or “task-related”) components (such as N2, P300, N400, P600) (Hillyard

& Kutas 1983). Exogenous components reflect the physical properties of sensory stimuli in the early stage of processing whereas endogenous components are influenced by cognitive manipulations, such as changing demands for attention, task relevance, and stimuli-specific processing in the later stage of processing. Example of the exogenous components is N1, which is a negative wave having a peak amplitude about 100 ms after the sound onset. N1 reflects processing and detection of sound feature as it is largest in response to the first stimulus of a series of sounds, strongly attenuating thereafter (Näätänen & Picton 1987). In music, task-related components, such as P300 and P600, reflect expectancy violations, e.g., unexpected violation in the melody, harmony or rhythm contour (Besson, Faïta & Requin 1994, Besson & Faïta 1995). Tonality "rule" violations have been found to elicit so-called early right anterior negativity (ERAN) that is suggested to reflect the violation of a musical sound expectancy according to tonality and musical structure (Koelsch & Friederici 2003).

N2 component can be divided into mismatch negativity (MMN; also termed N2a) and N2b. MMN is elicited before N2b and occurs as an automatic and preattentive response to a changed (or "deviant") tone in a sequence of repeated (or "standard") tones of a same sound. Thus, MMN acts as an indicator for preattentive detection of the changes in regular sequences of auditory stimuli. In general, MMN has been found for physical deviations in the sound sequences, such as change in frequency, duration, inter-stimulus interval, loudness, spatial locus of origin and timbre of single tones (Näätänen & Tiitinen 1998) or changes in more abstract sound entities (e.g., Näätänen, Tervaniemi, Sussman, Paavilainen & Winkler 2001, Näätänen & Tiitinen 1998).

It is not the feature of the sound itself but the difference that elicits the MMN. MMN is not restricted to physical changes but has also been found in more abstract changes or in rule breaking with pair of tones, polyphonic change (for example in chords), grouping of similar pitches and ascending pitch contours and short melodic contours (e.g., Näätänen et al. 2001). Example of an abstract rule violation is a finding that rule violations between two sound features ("the higher the frequency, the louder the intensity") elicits MMN (Paavilainen, Simola, Jaramillo, Näätänen & Winkler 2001). In general, the stronger response to violations in environmental stimuli might reflect the brain's economical way of allocating attentive resources only to the changed events in the regular environment (Huotilainen & Tervaniemi 2003).

The best way to record the MMN is to use unattended oddball condition in which deviant stimuli are presented randomly in a series of standard stimuli while participants do another demanding or interesting task. In this way overlapping of the attentive P2 and N2b components with MMN can be avoided (Näätänen, Brattico, Tervaniemi 2003). However, the scalp distributions may distinguish MMN and N2b (Ritter et al. 1992). MMN is mainly generated bilaterally in the supratemporal cortical areas, in which the primary and secondary auditory cortices are located (Huotilainen & Tervaniemi 2003). In EEG recordings MMN is seen as a polarity reversal from peak negative amplitude in fronto-central electrodes to peak positivity in mastoid electrodes (Tervaniemi 2000). This pattern of the electric field indicates that the MMN is generated in the supratemporal plane (Alho 1995). An additional generator has been localized in the frontal lobes. A frontal MMN subcomponent that is mainly right hemispheric is triggered by auditory-cortex change-detection process and is probably associated with the initiation of attention switch to the change (Escera, Alho, Schröger & Winkler 2000).

Sound processing in the auditory cortex

Human auditory cortex seems to have functionally specialized areas depending on the quality or spectral features (e.g., frequency, duration, intensity, timbre, polyphony) of the sound or on its temporal complexity (whether it is single tone or sound pattern). Analogous to the visual system, the auditory system might have parallel functioning pathways for the "what" information of tonal stimuli (such as intervals, melody contours, scales), the "when" pathway for temporal stimuli (such as rhythm, meter, tempo), the "where" pathway for locating sounds spatially and possibly a "how" system for processing the acoustic quality (such as timbre, polyphony and spatial movement of the sound) of the auditory material (Peretz, Champod & Hyde 2003, Rauschecker & Tian 2000, Belin & Zatorre 2000). MMN studies give further evidence for the specialized automatic, parallel processing areas as well as for functional differences according to stimulus quality and familiarity. For example, the MMN source in the brain seems to vary according to whether the stimuli are spectral (single tones, such as g as a standard and a as a deviant) or temporal and complex (presenting five chord tones either sequentially or in parallel changing the middle tone with deviants) in nature (Alho et al. 1996). MMN generators for sequential and parallel chords was on average 1 cm more medial (deeper) in the auditory cortex than for single tones. Despite the localization differences between sinusoidal tones versus sequential chords, the amplitude or latency do not differ between these stimuli. Comparison between musicians and non-musicians revealed that both groups processed dominantly sequential sound contours in the right hemisphere whereas MMN for isolated tones had no hemisphere differences (Brattico et al. 2001). Musical expertise affected latency in sequential patterns, musicians having shorter latency in the left hemisphere than non-musicians. Right-hemisphere dominance for melodic pitch sequence compared to fixed-pitch stimuli were found also in functional magnetic resonance imaging (fMRI) study (Patterson, Uppenkamp, Johnsrude & Griffiths 2002).

Latency and the magnitude of the MMN can vary also according to sound pattern. For example, Trainor, McDonald and Alain (2002) found that MMN occurred earlier with melody contour sequences when compared to interval sequences. Also the N1 (the initial orientation response to sounds) for the Contour deviants were larger than for the Interval deviants. Both sound patterns were 5-tone sequences transposed to 12 different scales. With the Contour deviant the last note changed to lower but harmonically related tone while in the Interval deviant the last note changed into out-of-key (inharmonic) tone. Results were interpreted so that melody contour sequences might require both short-term memory and abstract pattern-matching mechanisms thus enhancing the automatic processing. More recent study (Fujioka, Trainor, Ross, Kakigi & Pantev 2004) showed that musicians had larger MMNm than non-musicians for the Contour deviants in which the last tone was descending (compared to eight different standard melodies consisting of ascending tones) and for the 5-tone Interval deviants in which the last tone was raised by one whole tone (compared to standard melody that was transposed to eight keys). Furthermore, musicians had larger MMNm for the Interval deviants than for the Contour deviants. Contour and interval information might be processed independently: it has been found that a brain lesion in the left hemisphere did not affect melody contour processing but did so with interval processing whereas a lesion in the right hemisphere affected both (Liegeois-Chauvel, Peretz, Babai, Laguitton & Chauvel 1998).

Various studies have explored the brain lateralization of language and music, that is, whether language processing is predominantly processed in the left hemisphere and music processing in the right hemisphere. The current view suggests that the left-hemisphere dominance found for phonetic processing may be caused by the specialization of left hemisphere for processing rapid temporal changes (Tervaniemi & Hugdahl 2003, Zatorre, Belin & Penhune 2002). Correspondingly, small changes in frequency would be processed in the right hemisphere (Tervaniemi & Hugdahl 2003). An alternative view supported by several recent studies (Levitin & Menon 2003, Maess, Koelsch, Gunter & Friederici 2001) claims that there is overlapping of neural structures and processes in the perception of music and language. For example, Maess et al. (2001) found with magnetoencephalography (MEG) that music syntax is processed in the Broca's area, previously supposed to deal only with language material. It is possible that with musicians this overlapping may be enhanced. In an EEG study in which prosody and melody stimuli were compared between musicians and non-musicians it was found that musicians had enhanced detection of pitch changes for both musical and language stimuli (Schön, Magne & Besson 2004). Musical and language stimuli were similar according to their pitch contour, spectral characteristics and duration. In summary, it seems that processing would not be strictly modular as there are common areas processing general properties of the auditory material irrespective of the type of sounds used (Hall et al. 2003).

Neuroplasticity effects in musicians

Recent studies show that there are functional differences in early and late sound processing even among musicians depending on the behavioral practices and cognitive strategies. For example musicians have enhanced processing for the sounds of their own main instrument (Pantev et al. 2001), conductors have enhanced attention to spatially located sounds when compared to other musicians (Nager, Kohlmetz, Altenmüller, Rodriguez-Fornells, & Münte 2003) and musicians who improvise seem to have enhanced processing for complex melody contour changes (Tervaniemi, Rytkönen, Schröger, Ilmoniemi & Näätänen 2001). Also studies show structural differences in the brain between musicians depending on the onset of starting to play instrument and the intensity of the life-time playing (Schneider et al. 2002). These findings are reviewed in the following sections.

Structural evidence. Brain studies comparing musicians and non-musicians have shown several structural and functional differences. Structural evidence concerns the cerebellum, corpus callosum, planum temporale, gray matter and white matter volume differences. For example, larger anterior corpus callosum was found in musicians (Schlaug, Jäncke, Huang & Steinmetz 1995) as compared to non-musicians. Result was interpreted as an enhanced capability to transfer bimanual information that is needed in fast playing. Musical status has been found to correlate positively to gray matter volume in music-related brain areas. While professional musicians had the highest gray matter volume, amateur musicians had intermediate and non-musicians had the lowest gray matter volume in motor, auditory, and visual-spatial brain regions (Gaser & Schlaug 2003).

Functional evidence: Early components. Functional differences in the primary auditory cortex are found with several ERP components. Musicians having either absolute (i.e., recognize the pitch without referring to any other pitch) or relative pitch (i.e., recognize the pitch by referring to other pitch) have been found to have 25% larger N1m (the magnetic counterpart for the N1) for piano tones than for pure sinusoidal tones (Pantev et al. 1998). Non-musicians did not show any difference in N1m strength between the sound types. Also musicians who had started to play prior to their 9th birthday had stronger N1m than musicians who had started playing later than that. Moreover, musicians had enhanced N1m for the sound quality ('timbre') of their own primary instrument (Pantev et al. 2001). However, an intensive short-term training in pitch discrimination can enhance N1m also in non-musicians (Menning et al. 2000, Brattico et al. 2003).

Evidence for the differences in another early component between musicians and non-musicians was found in an MEG study, where amplitudes for early N19m-P30m components were significantly larger in professional musicians as compared to non-musicians and amplitudes were significantly larger especially in the right than in the left hemisphere for sinusoidal frequency stimuli (Schneider et al. 2002). However, N1m amplitudes were not significantly different between groups. Musicians were classified into professional, amateur and non-musicians according to educational and professional background. Another finding in this study was that participants who had high score from the Tonal subtest of AMMA test had 102% higher amplitudes and 130% larger gray matter volumes of anteromedial portion of Heschl's gyrus (or primary auditory cortex) as compared to non-musicians. Counterevidence for the practice effects on the N1 component (but obtained by using EEG) is the finding that musicians had larger amplitude of the N1c and P2 to tonal tones (whether the stimuli were piano, violin or pure tones) as compared to non-musicians but the N1 did not differ between groups (Shahin, Bosnyak, Trainor, & Roberts 2003).

Functional evidence: MMN findings. MMN studies have shown that preattentive cortical auditory processing is enhanced with musicians especially with musically relevant stimuli (Tervaniemi 2000). For example, professional violinists showed a significant MMN for slightly impure (0.75% change in pitch in the middle tone of the chord) chords presented among major chords whereas non-musicians did not (Koelsch et al. 1999). Musicians had also

N2b and P3b components, reflecting conscious detection process of the deviant stimuli, whereas non-musicians did not have those. Better neural automatic and attentive detection of the chord violation was reflected in the superior performance of the musicians in the behavioral task in which participants had to discriminate impure chords. In that study attentive discrimination did not increase the amplitude of the MMN for musicians. Further evidence for the superior processing of musically relevant stimuli in musicians was found in a study where a block consisting of sequences of four identical pitch tones or sequences of four ascending pitch tones were presented in counterbalanced order (Van Zuijen, Sussman, Winkler, Näätänen & Tervaniemi 2004). Both kinds of sequences varied in five different frequency levels. It was found that the MMN occurred for both musicians and non-musicians for the identical pitch sequence deviants including an additional fifth tone of the identical pitch. However, MMN occurred only for the musicians with ascending pitch sequence deviants including an additional ascending pitch tone. The result was explained by the importance of auditory grouping in retaining and recognizing melodic patterns for musicians.

However, according a recent finding (Tervaniemi, Just, Koelsch, Widmann & Schröger 2005), musical expertise does not guarantee the facilitation of preattentive pitch-discrimination functions: musicians had superior neural processing for deviant isolated tones (deviating 0.8%, 2% or 4% from the standard frequency) only in the attentional condition and not in the ignore condition when compared to non-musicians. Furthermore, the differences between groups were not found with the components indexing preattentive processing (such as MMN or P3a) but with the components reflecting more attentive processing change (such as N2b and P3) being larger with musicians. The behavioral discrimination task showed that musicians detected faster pitch changes but non-musicians were almost as accurate in their detection as musicians.

Most of the brain studies with musicians concentrate on spectral features of the sound. There are few studies about temporal processing with musicians (duration, rhythmic patterns). It has been found that musicians had stronger MMN to sound omissions with long stimulus onset asynchrony (180 ms vs. 220 ms) while non-musicians (as well as musicians) showed MMN when the SOA was shorter (100 ms and 120 ms) (Rüsseler, Altenmüller, Nager, Kohlmetz & Münte 2001). A recent MEG study showed that MMNm (the magnetic counterpart of MMN) to incongruent rhythms was enhanced and lateralized to the left hemisphere in jazz musicians while it was lateralized to the right hemisphere in non-musicians

(Vuust et al. 2005). Authors suggested that this MMNm enhancement and left-lateralization could reflect the expertise in perceiving subtle rhythmic pattern deviations that is an essential way of communicating musical ideas in improvisational jazz. Also later positive components can be affected by musical expertise. Professional rhythmic musicians (percussionists and bass guitar-players) and non-musicians had significant P3a to rhythmic violations but only musicians had a significant P3a to difficult beats (Jongsma, Desain & Honing 2004). Furthermore, musicians' superiority in discriminating meter structures behaviorally was reflected as larger P3a amplitudes. Non-musicians had larger P3a amplitude in duple meter context (which is the easiest) whereas musicians were equally good with easy and difficult contexts.

Functional evidence: Short-term learning. The neuroplastic effects observed in musicians have developed through long-term experience in playing and listening music actively. However, the consequences of practice can be seen in the auditory cortex already after a brief intensive training even with non-musicians within minutes (e.g., Pantev et al. 2003, Gottselig, Brandeis, Hofer-Tinguely, Borbély & Achermann 2004, Brattico et al. 2003). Plastic effects can be reflected as larger responses soon after training. MMN studies have shown an increase in the amplitude of the MMN after attentive discrimination (Näätänen, Schröger, Karakas, Tervaniemi & Paavilainen 1993, Tervaniemi et al. 2001, Gottselig et al. 2004). For example, in the Näätänen et al. (1993) study the MMN was elicited in the ignore condition only after one or two attentive discrimination condition where participants could train behaviorally to discriminate the sound patterns. Also learning is related to the behavioral discrimination accuracy and the difficulty of the to-be-learned stimuli. This was observed in an EEG study where non-musicians listened in oddball paradigm to eight-tone sequences that were presented in high and low frequency level (Gottselig et al. 2004). In the deviant sequence one tone was changed into different frequency. Between two ignore conditions there was one 6-minute attentive discrimination condition where one group of participants were instructed to discriminate low frequency deviants and the other half were instructed to discriminate the high frequency deviants among standard sequences. In the EEG recordings both deviants were presented. Behavioral performance showed that low frequency deviants were significantly easier to discriminate than high frequency deviants and the MMN was stronger for the easier deviants. Also the MMN increased significantly for the easier deviants after attentive discrimination in the group that practiced that deviant. MMN for the difficult deviants did not grow after attentive discriminations. Furthermore, initial behavioral discrimination and initial MMN correlated significantly in the easy deviant group while no correlation was found in the group that practiced the difficult deviants. Authors suggested that difficulty of the deviant was the main reason behind the discrimination and learning differences between the groups.

Long-term practice effects. Results show that long-term training and practice changes the neural activation areas. In a transcranial magnetic stimulation (TMS) study it was found that mimicking piano playing with auditory feedback for two hours per day during five days led to larger cortical representation (that is activation area) in the finger muscles related to playing (Pascual-Leone et al 1995). However, cortical representations for activated fingers were found to decrease for the participants who continued training daily half an hour for five weeks. According to the authors, this could mean that subcortical structures begin to control as motor functions get automated after training. This suggestion is consistent with the idea that increasing the connectivity of pyramidal cells (from which EEG gets input) will increase their functional capacity (Kolb & Whishaw 1998). This means that in the expert's brain the neural nets may not be simply larger but also structurally organized in a more sophisticated way with more dense connections. In another study, musicians who play string instruments (such as violin, cello, guitar) were found to have larger cortical representation of the digits of the left hand than non-musicians in MEG study (Elbert, Pantev, Wienbruch, Rockstroh & Taub 1995). This was explained by the fact that string players use their left hand fingers (except the first digit) in fingering the strings of the musical instrument. Furthermore, the cortical areas for finger representations related with the age of starting to play. Musicians who started playing prior to the age of 12 years, had wider spread cortical areas for finger representations than the musicians who started later. There was no relation between the amount of practice and the cortical measures. Other studies (e.g., Pantev et al. 1998, Schlaug et al. 1995) suggest enhanced neuroplastic effects when playing was started before 7-9 years.

In a similar fashion, larger and faster MMN with musicians may also reflect that the neural traces get enhanced and organized in a more efficient manner after active and intensive practice of playing. This in turn makes music processing automated and at the same time reinforces expectations of familiar continuations. Automated processing deliberates the capacity (possibly larger neural resources) for learning higher functions, such as more complex structures (Huotilainen & Tervaniemi 2003). Following chapter reviews neurocognitive studies comparing musicians and non-musicians.

Neuroplasticity effects among musicians

There is very little research focusing on self-learned performing musicians or pop and jazz musicians. The interest for studying the differences among musicians stems from preliminary evidence indicating that fine-grained plastic effects may occur among musicians depending on the instrument, age of commencement of playing, and intensity of practice. Musical experience may qualitatively alter neural processing. For example conductors had more fine-tuned attentive sound-location processing for spatially located sound bursts than pianists and non-musicians (Nager et al. 2003). Spatial locations were implemented using nine loudspeakers in a semicircle in front of the listeners. This may be explained by the fact that conductors are familiar in spatial localization of sounds during conducting an orchestra. Similarly, musicians have larger auditory cortical representation for the primary instrument that musician plays (Pantev et al. 2001) because of familiarity of the own instrument timbre.

The type of musical expertise may affect neural processing also during learning and perception of complex sound patterns. Musicians who did not use scores (for example jazz musicians, improvisers, musicians playing more by ear) seemed to detect better changed contours in randomly transposed melodic patterns when compared to musicians who used scores when playing (Tervaniemi et al. 2001). The superiority was seen during the EEG study in both attentive conditions as a higher hit rate in behavioral task and in the ignore condition as an enhanced MMN. It was found also that the MMN occurred only after the first attentive discrimination condition which suggests, according to the authors, that conscious attention may be a necessary prerequisite for complex preperceptual learning to occur.

One possible explanation for the benefit of improvisation in perceiving complex melody patterns, comes from the study where aural imitation ability (that is playing back a heard musical item) was found as the second most important predictor of achievement in instrumental jazz improvisation, next to self-evaluation as a improviser (May 2003). The term 'aural' relates to *sense of hearing* (Merriam Webster's Collegiate Dictionary 1993). Hence, aural strategies would be playing without notes and relying mainly to the auditory perception. It was also found that neither improvisation class experience, jazz theory achievement, aural skill test performance, instrument or piano experience significantly affect improvisation performance scores. Aural imitation ability (or "playing by ear") needs accurate aural analysis and transforming this into motor sequences. In addition to aural training, improvisation learning includes often analysis of performance strategies within different musical context (rhythm, meter, tonality etc.) by listening, transcribing (writing the listened notation down) and reproducing recordings of famous improvisation musicians'. Learning by ear is a justified way to learn improvisation because notation in jazz music is only suggestive. Although all musicians may use analytic listening when practicing playing, particularly improvisation may require playing by ear (transferring heard auditory material into motor sequences) and using a theme or free idea during improvisation (transferring internal auditory material into motor sequences). In contrast, in improvisation, sight-reading processes are less employed (transferring visual material into motor actions). These aspects are taken into consideration with the research problems that are introduced in the following chapter.

Neurocognitive findings reviewed earlier suggest that musicians and possibly other expert groups should be studied as a more heterogeneous group and not simply clustered as a unitary group. Even the dictionary definition of musician reveals such diversity: a musician can be "a composer, conductor, or performer of music" (Merriam Webster's Collegiate Dictionary 1993). In many studies musician participants vary according to their music training, their main instrument, years of practice, hours of practice per day, theoretical knowledge of music, and whether participants are students or professionals. Some studies have used separate groups for amateurs and actively performing professional diploma musicians (for example Schneider et al. 2002). In most of the brain studies musicians are trained in classical music, and play either the violin or the piano. In this investigation also musicians having other than classical education were recruited as participants. Particular interest was to find out the effects of using aural performing strategies (consisting of improvising, playing by ear and practicing by listening recordings) on the automatic auditory processing of isolated sound features and of complex sound patterns.

Research problems

Based on the previous literature review, four research problems with were formulated. Problems address both neural and behavioral issues.

Question 1. Do musicians differ according to whether they prefer using aural or non-aural practice strategies? The first aim in this study is to explore the musicians' preference to use aural and non-aural strategies and to group musicians accordingly into aural and non-aural groups. This information is gathered with an extensive musical background questionnaire. Aural strategy means practice and learning strategies that pertain mainly to the auditory perception. Hence, the criteria for aural group were a priori defined as consisting of improvising, playing by ear and rehearsing by listening recordings plenty.

Question 2: Does the preattentive neural sound processing for sound features differ between musicians preferring aural vs. non-aural practice strategies? This question is studied with EEG recordings in MMN paradigm, using isolated sounds and complex sound patterns. For measuring long-term neuroplastic changes in the auditory cortex, MMN component was considered to be ideal. MMN indicates mainly preattentive detection of changes in the auditory material.

Question 3: Does the preattentive processing and learning after attentive discrimination of complex sound patterns differ between musicians preferring aural vs. non-aural practice strategies? Complex sound patterns (the so-called 'transposed melody') paradigm is used to measure the learning effects after attentive discrimination of sound patterns. The paradigm was modified from Tervaniemi et al. (2001) study. The idea is to find out whether cognitive and perceptual strategies (acquired those through long-term learning and training) affect the short-term perceptual discrimination accuracy and learning with complex sound patterns. Preliminary evidence for this question was found in Tervaniemi et al. (2001) study where musicians who did not use scores and improvised were superior at discriminating deviant melodic patterns and their MMN amplitudes grew more after attentive condition than musicians who were found to use musical scores and did not improvise. This was interpreted as an enhanced learning of complex sound patterns. In this investigation musicians who do not use scores (or practice plenty according to aural information) are classified as musicians preferring aural strategies.

Question 4: Are there behavioral differences among musicians preferring aural vs. non-aural practice strategies? This question is studied by behavioral discrimination task during the attentive condition in the EEG recordings and with the Advanced Measure of Musical Audiation (AMMA) musicality test. The rationale here is that AMMA is claimed (Gordon 1989) to be based on audiation that develops via improvisation and playing by ear. Also AMMA test items represent complex melody contours that are expected to correlate to attentive discrimination performance in the transposed melody paradigm. There are studies which show correspondences between behavioral performance and preattentive sound processing (e.g. Lang et al. 1990). The relationship between preattentive sound processing and both the AMMA test and attentive discrimination task during the complex sound patterns were investigated. The next chapter introduces the study methods, participants, the used procedure, apparatus and stimuli.

Methods

Methods included a web-based questionnaire, a musicality test, and EEG recordings in two different paradigms.

Participants

Altogether 33 students participated in this study. They studied in the Sibelius Academy (10 females, 3 males), the Conservatory of Helsinki, other Finnish conservatories (4 females, 3 males), and the Helsinki Pop & Jazz Conservatory (3 females, 9 males) participated in this study. One female participant was studying at the University of Helsinki but was accepted as musician because of her professional performing. Hence criteria for musicianship were that the participant was either studying to be a professional musician or was employed full-time as a musician. Study programs varied largely, from church musicians, music teaching, composition, music technology, music theory to solistic programs in which half of the participants were studying. There were 11 participants who had either a Basic degree or a Bachelor degree or a Master degree in music. The others were undergraduate students. Study years in the current school varied from 1 to 10 years (M = 2.9, SD = 2.3). Age range was 18-30 years (M = 23.5, SD = 3.2 years). All except two female participants were right-handed, one male reported to be ambidextrous. All had normal or corrected vision. None of the participants had diagnosed dyslexia. Three of the participants took part in the pilot measurements, after which minor changes to the experiment were made. Three participants had to be excluded from the final analysis because of excessive artifacts in the EEG data. Three individuals were excluded from the further analysis because they did not clearly belong to neither of the defined groups. Altogether 24 participants were further analyzed. Participants were recruited by adding paper invitations and sending email invitations to the student mailing lists of aforementioned schools. All participants received 30 euros per approximate five hours for taking part in this study.

Questionnaire

Participants filled a web-based questionnaire (see Appendix 1) to assess their musical background and playing strategies. On the basis of the results of this questionnaire participants were divided in aural and non-aural groups. Aural strategy was defined by theoretically chosen variables, i.e., improvising, playing by ear and rehearsing by listening recordings. Accordingly, criteria for the aural group were the following: improvised several times a day or once a day, played by ear often or quite often, and practice playing by listening recording (own or others) at least 10% or more. Those who reported improvising, playing by ear or practicing by listening recordings seldom or never were categorized into non-aural group. Finally 13 participants were included in the aural group and 11 participants in the non-aural group.

The question items were reviewed by two experts in music theory and performance. Experts were a lecturer and researcher from the Sibelius Academy and a researcher from the Cognitive Brain Research Unit, University of Helsinki. The questionnaire was written in English but participants could give Finnish answers to open-ended questions. Participants were encouraged to ask whenever they needed translation or clarification of the questions. Participants could choose also to answer orally. In these cases instructor typed given answers as such. Confidentiality of the results was emphasized before starting to answer.

The questionnaire was divided into themes, such as demographic status, musical background, educational and professional background, playing, practicing and learning strategies, own musical preferences and musical experiences in the childhood. Participants gave self-perception of their abilities in different musical areas, such as improvising, sight-reading and primavista, participation in band or choir and music listening. There were questions concerning formal music education, such as studying ear training courses and music theory courses. There were fixed choice, multiple choice and open-ended questions. Open ended questions mainly concerned mainly strategies and preferences.

Advanced Measure of Musical Audiation (AMMA)

Advanced Measure of Musical Audiation (AMMA) musicality test was performed in order to explore whether there are any differences at the behavioral level in melody pattern tasks and whether behavioral results correlate to preattentive sound processing. From many available musicality tests, AMMA was chosen because of it claims to represent the so-called stabilized musical aptitude and it thus is best suitable to study professional musicians. Also the test creator (Gordon 1989) argues that the mechanism (audiation) needed to correctly perform the AMMA test develops through playing by ear and improvisation which are key concepts in this study. According to the AMMA manual (Gordon 1989), this test has adequate norm data, its reliability and validity examinations have been reported adequately, it is independent of musical training and chronological age, has clear instructions and takes only 20 minutes. The norm sample consists of American college and university music majors (n = 3206), non-music majors (n = 2130) and high school students (n = 872). Reliability of the test is measured by the split-halves and retest measures that produced nearly the same coefficients for all the norm groups. It was noticed that current scoring produces high intercorrelation scores between Rhythm and Tonal test scores and better discrimination of these measures can be obtained by dropping of scoring of the "same" answers and not using any adjustment or constants. However, Gordon (1997) recommends using the established scoring protocol (Gordon 1989) because it gave a longitudinal predictive validity coefficient of .82 for the Total scores with the performance evaluation ratings. This validity study result should be interpreted cautiously because it lacked inter-rater examinations.

AMMA begins with three practice trials after which there are 30 trials. The order of tonal and rhythm items as well as difficult and easy items are randomized. Participants hear two short musical melodies played by a piano synthesizer after which there is a 4 second silence. The task is to compare whether the melodies are the same or different. If they are different participants have to choose whether the difference is tonal or rhythmic. Tonal items include pitch (a perceived frequency of the tone), mode (musical scale), or tonal center (harmonic relationship between musical scale and individual tones) changes. Rhythm items include duration, meter (perceived regularity in the accents) or tempo (fastness) changes. There is only a tonal or a rhythmic change in one item.

EEG recordings

Apparatus

EEG measurements were performed in an electrically shielded room. EEG was recorded from a 32-electrode cap (Lectron, Finland) and from both left and right mastoids. The reference electrode was placed on the tip of the nose. The horizontal electro-oculogram (EOG) was recorded using electrodes placed at the outer canthi of the left and right eyes, and the vertical EOG was monitored from the Fpz location. The EEG was amplified, digitized (sampling rate of 500 Hz; online filter 0.1-100 Hz) and offline bandpass filtered between 1-20 Hz (24 dB/octave) using NeuroScan Acquire and Edit programs. Data were averaged in epochs with a 100 ms prestimulus interval separately for each of the deviant and standard stimuli. Epochs for the optimal paradigm were -100 – 400 ms and for the transposed melody patterns paradigm -100 – 1200 ms. All stimuli were baseline corrected from 100 ms before the deviant tone onset to the beginning of the deviant tone. Epochs with an EEG or EOG change exceeding 100 μV were excluded from the averaging.

Because the main interest was to see the difference between standard and deviant stimuli, difference waveforms were computed by subtracting the standard ERP from the deviant ERP. Subtraction waves were done individually for each deviant. The subtraction waves were then re-referenced to the averaged value of both mastoids. A grand average for each experimental group was computed from all the individual averages in order to extract the group peak amplitudes and the corresponding latency during 100-200 ms after the deviant sound onset. Time window for extracting the individual MMN peaks from the subtracted waves were defined as ±20 ms around the group MMN peak latency from the fronto-central electrode (12). Individual peak amplitudes and latencies were used in the statistical analysis.

Stimulation

Stimuli for the optimal and transposed-melody paradigm were produced with CoolEdit 2000. The stimulation sequences for the transposed-melody paradigm were constructed with the SequenceMaker program (programmed by Tuomas Teinonen, Helsinki University of Technology). For both the paradigms, stimuli in EEG recordings were presented with the BrainStim program (programmed by Sampo Antila, Cognitive Brain Research Unit, University of Helsinki) program.

Optimal paradigm. Two paradigms were chosen for the EEG recordings: the optimal paradigm and the transposed-melody paradigm. The optimal paradigm (Näätänen, Pakarinen, Rinne & Takegata 2004) was chosen to screen automatic processing of isolated sound features. In particular, optimal paradigm explores the preattentional change detection of five sound features: frequency (10% higher or lower than standard repeated tone), duration (25 ms longer or shorter than the standard tone), sound source location (90° degree to the left or right from the binaurally perceived standard tone), intensity (10 decibel louder or softer than standard tone) and gap in the middle of the tone (cutting out 7 ms out of the middle of the tone). Unlike in the traditional oddball paradigm where the deviant tone comes only rarely and randomly in the sequence of several standard tones, in the optimal paradigm the standard and deviant tones occur in alternating order (see the Figure 1). Every deviant in the optimal paradigm is presented at 10% probability so that every other tone is a standard (of 50% probability). Tones consisted of three harmonic partials, were 75 ms in duration and were presented with a stimulus onset asynchrony (SOA) of 500 ms.

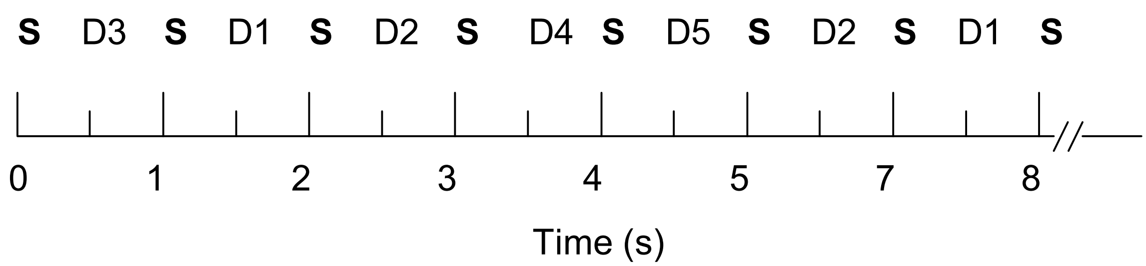

Figure 1. Illustration of optimal paradigm (adapted from Näätänen et al 2004). A randomly chosen deviant (D1-D5) occurs after every standard tone (S) so that there is no same deviant occurring twice in the sequence of ten tones.

Transposed-melody paradigm. In order to study preattentive discrimination of complex stimuli a transposed-melody paradigm was used. Transposed melodies were adapted from the Tervaniemi et al (2001) study. One new deviant (termed Interval deviant) was added to the paradigm in order to compare the differences between the strength of the responses to the Interval and the so-called Contour deviant that was the same as in the original study of Tervaniemi et al. (2001). Previous study of Trainor et al. (2002) has shown that the changes in the melody contour sequences elicited MMN earlier than changes in the interval sequences.

Each melodic pattern consisted of five different 50-ms sinusoidal tones separated by 50-ms silent interval. The interstimulus interval (ISI) between melodic patterns was 750 ms. All the melody patterns were constructed according to the major key and had no out-of-key or random tones. Patterns were transposed randomly on 12 frequency levels (varying between 330 Hz – 1100 Hz). Transposition of melodies was employed for avoiding simple association and for allowing studying perception of melody pattern ('Gestalts'). All the standard patterns were following an ABCED structure in abstract terms. In the Contour deviant the 4th tone of the melody pattern was different (ABC**A**D in abstract terms) and in Interval deviant the last, 5th, tone was different (like ABCE**A**). Figure 2 illustrates the standard and deviant patterns.

The standard melody patterns were presented with 86% probability and both deviants were presented with 7% probability.

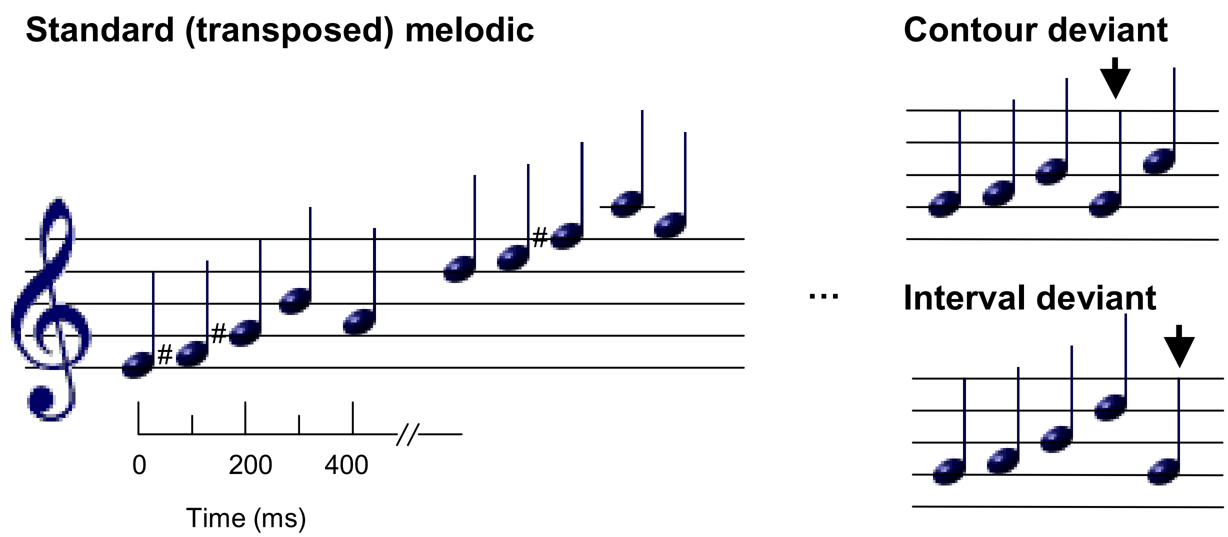

Figure 2. Examples of the standard (in the left) and deviant (in the right) melodic patterns. Contour deviant was adapted from Tervaniemi et al. (2001) study whereas Interval deviant was added as a new stimulus. All melody patterns were in major scale. The arrows indicate the place where deviant melody pattern has a different tone compared to standard melody pattern.

Procedure

All participants signed a written information consent form (Appendix 2) and read the instructions before the EEG recordings (Appendix 3). Instructions were both in Finnish and in English. Further details about the study were emailed beforehand to the participants.

EEG recordings were held as a first part of the study. Recordings started with the optimal paradigm that took 15 minutes. After this, the transposed-melody paradigm was presented. Participants were instructed to avoid movements of any kind. During the optimal paradigm and the ignore conditions of the transposed-melody paradigm, participants watched a self-selected silent and subtitled DVD movie while presented with the stimuli via headphones with a 65 dB sound pressure level.

The transposed-melody paradigm included a first ignore condition (two blocks of 24 + 12 minutes) followed by an attentive condition (12 minutes) where participants were instructed to look at a fixation point, listen to the sounds and push a button immediately after hearing any deviant stimulus. Participants were not told in the sequences there were two different kinds of deviants. This instruction was intentionally kept as non-directive. The attentive condition enabled to find out to what extent stimuli were consciously detected and whether attentive discrimination enhances the discrimination in the second ignore condition (two blocks of 24 + 12 minutes) that was presented after the attentive condition. ERP responses were not analyzed from the attentive condition but only the behavioral performance. The two ignore conditions were divided into 24 or 12 minute blocks in order to allow short breaks for the participant. The stimuli were pseudo-randomized so that the 5 first patterns were standard stimuli. Altogether 1800 melody patterns were presented during each ignore condition and 600 patterns in the attentive condition. The whole duration of the EEG recordings was about 3 hours including the preparation and the breaks.

The behavioral tests were held in a separate day. After that participants performed the AMMA musicality test, lasting 20 minutes, and the questionnaire, taking about 30 to 90 minutes.

Statistical analysis

Data were statistically analysed with the SPSS 11 program by using repeated measures, univariate analysis of variance (ANOVA), paired t-test, independent t-tests or Mann-Whitney U test (for ordinal level variables). Correlation values were reported as Pearson correlation coefficient. Group was used as an independent variable in all analyses except the paired t-tests.

In the EEG recordings, amplitudes and latencies for statistical analysis were extracted from nine electrodes that located frontally (5, 6, 7), frontocentrally (11, 12, 13) and parietally (17, 18, 19) (see Figure 3). These electrodes were chosen according to empirical results of the MMN component topography. Laterality explorations of differences in sagittal direction (anterior vs. posterior electrodes) were done using this division and in coronal direction (for hemispheres) using left (5, 11, 17), central (6, 12, 18) and right (7, 13, 19) division. Post hoc tests were computed with paired t-tests with a priori planned comparisons: for laterality comparison before-mentioned divisions were used to compare electrodes and for comparing deviants in pairs, the frontocentral electrode 12 was used.

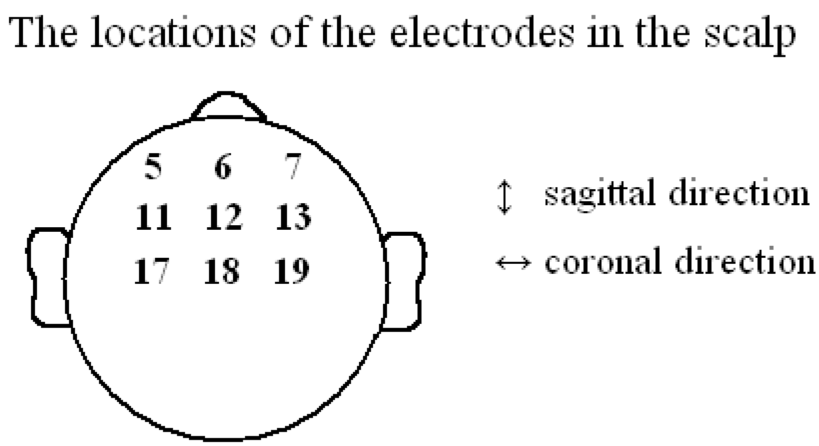

Figure 3. The locations of the electrodes. Nine electrodes were chosen to statistical analysis according to the theoretical knowledge of the MMN topography.

Both optimal and transposed-melody paradigms were analyzed with the repeated measures ANOVA using deviant type (frequency, intensity, direction, duration and gap in the Optimal paradigm and Contour and Interval in the transposed-melody paradigm), sagittal direction (frontal vs. frontocentral vs. parietal electrodes) and coronal division (left vs. central vs. right electrodes) as a within-subject factors and group (aural vs. non-aural) as a between subject factor. In the transposed-melody paradigm condition (before and after attentive condition) was added as within-subject factor. Latencies for deviant types in transposed-melody paradigm were equalized by subtracting 100 out of Interval deviant latency value. This was because the deviant tone in Interval deviant occurred 100 ms later than with Contour deviant. Only behavioral data were analyzed from the attentive condition in the transposed-melody paradigm. Button presses occurring 100-1200 ms after deviant pattern were classified as hits. Greenhouse-Geisser epsilon correction for non-sphericity was used to adjust P-values when applicable. Means and standard deviations are presented for the frontocentral channel 12 unless otherwise stated. The presence of the MMN component was explored with one-tailed t-tests against zero.

Results

Questionnaire

There were two goals for the background questionnaire: to formulate groups according to their preference to use aural or non-aural performing strategies and to explore the participants' musical background. Manual classification was validated by Mann-Whitney U group comparisons that indicated that the aural group improvised significantly more (U = 2.0, p<.001, with 17.9 vs. 6.2 points for the aural and the non-aural group, respectively), played more by ear (U = 24.5, p<.005, with 16.1 vs. 8.2 points) and practiced more by listening the music piece recorded (U = 30.0, p<.004, with 15.7 vs. 8.7 points) than the non-aural group. In general, the aural group employed significantly more aural strategies (consisting of overplaying, listening by recordings, improvising, doing music arrangement and composing own pieces) as part of the daily practice as compared to non-aural group (U=44, p<.04, with 13.8 vs. 10 points). Furthermore, the aural group reported significantly more practicing to play mentally (U=29.5, p<.01, with 15.8 vs. 8.6 points) and improvising together with other musicians while non-aural group reported to improvise usually alone (U=28, p<.04, with 12.9 vs. 8 points). The aural group reported to compose significantly more hours per week than the non-aural group (U=18, p<.004, with 14.6 vs. 7 points). A composite scale was constructed for theory studies including music analysis, figured bass, primavista, counter point and ear training courses. According to this scale, the non-aural group had significantly more theory studies than aural group (U=20, p<.01, with 8.2 vs. 15.5 points). However, participants were significantly (U = 32.5, p<.02, with 9.0 vs. 15.5 points) unequally distributed into groups according to their musical background: the aural group included more musicians from the pop & jazz conservatories whereas the non-aural group had more students from Sibelius Academy.

Mann-Whitney U group comparison revealed that the groups did not differ by their age of starting to play the main or second instrument, main or secondary instruments played, practicing hours per week for main or secondary instrument(s), the number of secondary instruments, the amount of musical working experience or participating musical activities, memorizing techniques, study years in the current school, nor for childhood musical background variables, such as participating at music schools, having musicians in the family or listening to music at home.

AMMA test

The scores in AMMA Tonal subtest and its Total score differed significantly between groups (see Figure 4). Tonal scores were significantly [F(1,22) = 4.71, p<.05] higher in the non-aural group (M = 78.0, SD = 18.0) than in the aural group (M = 63.85, SD = 13.93). Rhythm scores were not significantly different between groups. Total scores differed significantly [$F(1,22) = 4.82$, $p<.04$], the non-aural group having higher ($M = 71.91$, $SD = 18.98$) scores than the aural group ($M = 57.62$, $SD = 12.76$).

The range for all the scores varied highly: for the Tonal subtest the score was 59, for the Rhythm subtest 71 and for the Total score 60 of the percentile range. High intercorrelation ($r = 0.84$, $p<.001$) was found between Tonal and Rhythm subtests, meaning that those musicians who performed well in the Tonal subtest performed well also in the Rhythm subtest and vice versa.

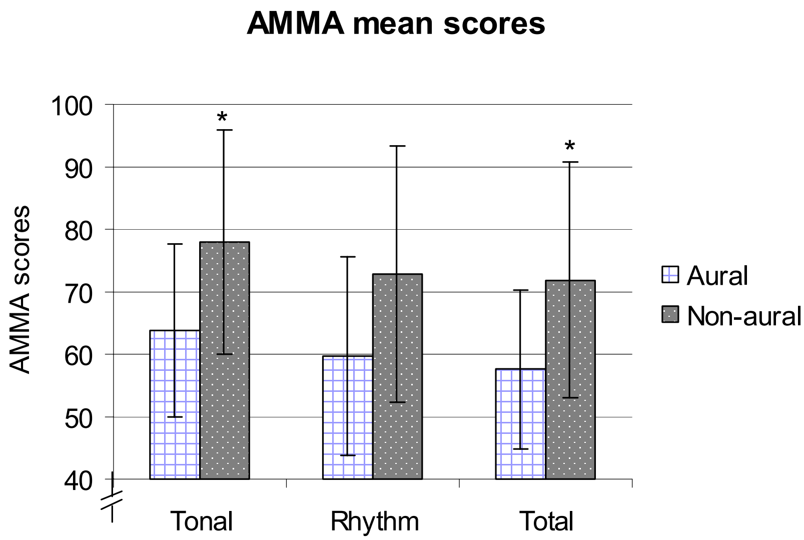

Figure 4. Mean scores for the Tonal and Rhythm subtests as well for the Total score of the Advanced Measures of Musical Audiation (AMMA) test (SD marked on the top of the bars). The significant group differences are marked with *.

AMMA subtests and the Total score did not correlate significantly to the grouping variables, such as improvising or playing by ear but the Total score correlated negatively ($r = .34$, $p<.05$) with the practice by listening to recordings. Rhythm subtest correlated significantly ($r = .40$, $p<.03$) with the age of starting to play in a band or orchestra. This means that participants who had started to play at an earlier age had higher scores in the Rhythm subtest. Behavioral discrimination accuracy in the EEG recordings, sex, chronological age, age of starting to play the main instrument, practicing hours per week or the degree of the latest musical exam did not correlate (or related with the χ^2 test) to AMMA scores.

MMN amplitude. As Figure 5 illustrates, both groups had significant ($p<.001$ for all electrodes) MMNs for all deviants in the optimal paradigm however, without significant group differences in the MMN amplitude. There was a tendency of enhanced Gap and Location MMN in the aural group as compared to the non-aural group but it is not significant because of large inter-individual variation. Interestingly, the MMN to the Duration deviant was more negative ($M = -6.30$, $SD = 1.37$; channel 12) with the non-aural group than in the aural group ($M = -5.08$, $SD = 1.13$).

A significant main effect in the MMN amplitude was found for the deviant type [$F(4,88) = 14.19$, $p<.001$; repeated measures ANOVA], sagittal division [$F(2,44)=11.24$, $p<.001$] and coronal division [$F(2,44)=8.29$, $p<.002$]. The interactions between deviant type and sagittal division [$F(8,176)=12.26$, $p<.001$] and between deviant type and coronal division [$F(8,176)=2.45$, $p<.02$] were also significant.

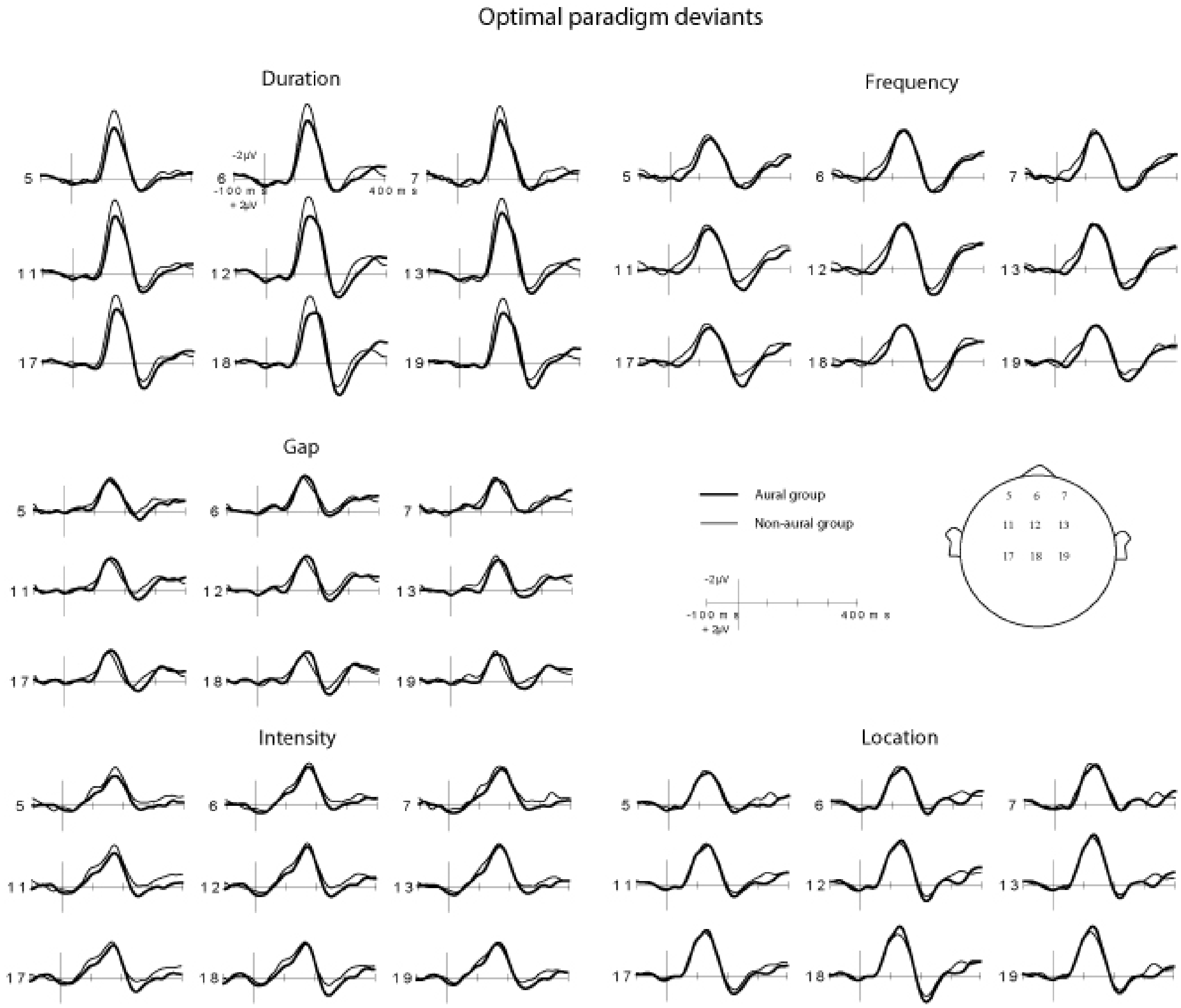

Figure 5. Difference waveforms for both groups in Optimal paradigm. In difference waveforms standard has subtracted from the deviant so only the difference between standard and deviant ERPs is illustrated.

In all participants, the Duration-MMN was significantly larger in amplitude than the MMN to Location [t(23)=-4.09, p<.001], Intensity [t(23)=-7.25, p<.001], Gap [t(23)=-6.78, p<.001], or Frequency [t(23)=-3.92, p<.002] (at electrode 12). Also the MMN amplitudes to all the deviants except the Location one were larger at the frontal electrodes than at the posterior electrodes (see Table 1). The MMN to the Location deviant was strongest in the posterior electrodes. Except for the Gap deviant, MMN was strongest in the right hemisphere for all deviants.

Table 1.
Paired t-test values for the MMN topography in the Optimal paradigm (electrodes used in each pair comparison are shown in parentheses)

Deviant	Coronal direction			Sagittal direction		
	Frontal left vs. right (5 vs. 7)	Fronto-central left vs. right (11 vs. 13)	Parietal left vs. right (17 vs. 19)	Left frontal vs. parietal (5 vs. 17)	Central frontal vs. parietal (6 vs. 18)	Right frontal vs. parietal (7 vs. 19)
Duration	3.31*	1.97	-1.25	0.88	-2.19†	-2.04
Location	4.47**	4.05*	0.49	7.39**	2.88*	2.28†
Intensity	2.80†	2.30†	0.22	0.04	-2.48†	-1.99
Gap	0.52	-0.89	-1.92	0.21	-2.19†	-2.19†
Frequency	2.57†	2.26†	0.64	-1.12	-4.79**	-6.43**

T(23)= † p<.05, * p<.01, ** p<.001

MMN latency. There were no significant MMN latency differences between the subject groups. Only a significant main effect was found for the deviant type (F(4,88) = 55.61, p<.001). This resulted from the significantly shorter Duration- than Intensity [t(23)=-8.49, p<.001] or the Gap-MMN [t(23)=-3.28, p<.004] latencies (this and other post-hoc tests at electrode 12). Further, Location-MMN latency was significantly shorter than Intensity- [t(23)=-11.58, p<.001], Gap- [t(23)=-8.14, p<.001] or Duration-MMNs [t(23)=5.20, p<.001]. The Frequency-MMN latency was significantly shorter than Duration- [t(23)=3.02, p<.007], Intensity- [t(23)=8.65, p<.001] or Gap-MMNs [t(23)=-4.90, p<.001]. Also, Gap-MMN latency was significantly shorter than Intensity-MMN latency [t(23)=4.59, p<.001].

EEG recordings – Transposed-melody paradigm

As Figure 6 illustrates, both groups had significant MMNs for both Contour (p<.006 for all electrodes) and Interval (p<.004 for the aural group and p<.05 for the non-aural group) deviants already before attentive condition in the transposed-melody paradigm. After attentive condition, the Contour-MMN was also significant for both groups (p<.05 for all electrodes except 6 for the aural group and p<.003 for all electrodes for the non-aural group). The Interval-MMN decreased in amplitude especially in the aural group and only three electrodes in both groups indicated significant (p<.05) MMN.

MMN amplitude. There were no significant differences in MMN amplitudes between groups in different conditions. Also no laterality effects for amplitudes were found. Only a significant main effect for the amplitudes was found for the factor deviant type [F(1,22)=5.42, p<.04]. This resulted from the Contour-MMN being larger in amplitude after attentive condition than the Interval-MMN [t(23)=-2.59, p<.02] for all participants (this and other post-hoc tests at electrode 12).

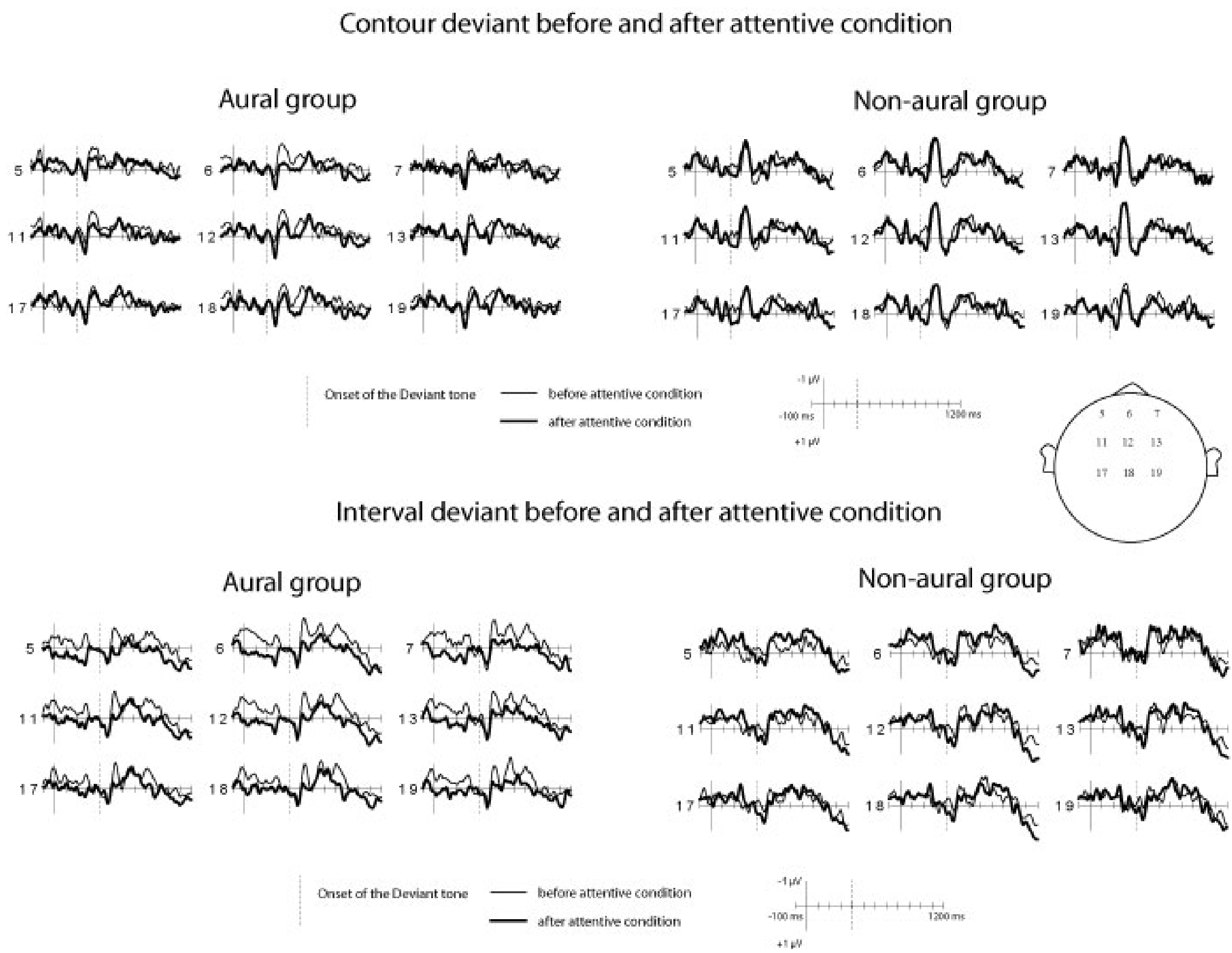

Figure 6. Difference waveforms for contour and interval deviant in transposed melody paradigm. Before attentive condition waveform is marked as thin line and after attentive condition waveform is marked as bold line.

Figure 7 illustrates the mean peak amplitudes in both groups in ignore conditions before and after attentive condition. This comparison reveals whether there are changes in MMN amplitudes and latencies between the ignore conditions. The Interval-MMN was significantly smaller in the aural group after attentive condition [t(12)=-2.23, p<.05 for the electrode 12; paired t-tests, 2-tailed] than before attentive condition. Non-aural group had no significant differences in amplitudes between these two ignore conditions. Contour-MMN did not differ in amplitude between two ignore conditions with neither of the groups.

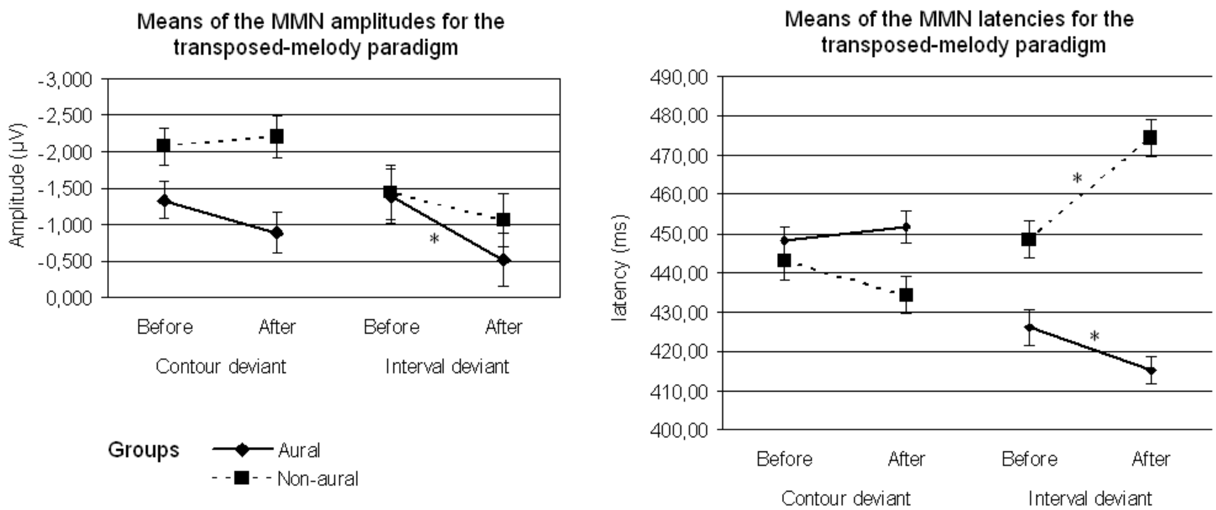

Figure 7. Mean amplitudes and latencies for the Contour and Interval deviants in before and after attentive condition for the electrode 12 (bars indicate the standard error of the mean, SEM). Aural group is illustrated as a solid line and non-aural group is marked as a dashed line. Significant change between conditions is marked with *.

MMN latency. MMN latency differed between the groups [$F(1,22) = 29.19$, $p<.001$]. Moreover, significant interactions were found between the deviant type and group [$F(1,22) = 86.08$, $p<.001$], condition and group [$F(1,22)=10.98$, $p<.004$], and deviant type, condition and group [$F(1,22) = 24.84$, $p<.001$]. Also significant laterality effect was found between condition, sagittal division and group [$F(2,44)=3.84$, $p<.05$].

Post hoc tests showed that the aural group had significantly shorter latency with Interval-MMN before and after the attentive condition compared to non-aural group (see Table 2). However, the non-aural group had significantly shorter Contour-MMN after attentive condition than the aural group.

Table. 2.
Post hoc t-test comparing MMN latency for aural and non-aural group.

Groups	Frontal electrodes			Frontocentral electrodes			Parietal electrodes		
	5	6	7	11	12	13	17	18	19
	Contour deviant before attentive condition								
Aural	443.23	444.15	439.85	440.62	448.15	433.23	442.15	442.00	438.31
Non-aural	440.36	437.64	440.91	440.55	443.09	435.45	441.27	442.00	441.45
	Contour deviant after attentive condition								
Aural	449.69*	447.85*	446.15*	447.38**	451.69*	447.54*	450.31*	452.15**	449.85**
Non-aural	436.18	431.64	430.55	434.55	434.36	431.09	432.91	431.82	428.73
	Interval deviant before attentive condition								
Aural	528.92	527.54	526.77	525.38	526.00	524.77	530.31	529.23	526.62
Non-aural	546.00†	546.18†	548.00†	546.36	548.55†	549.09†	551.64*	554.18*	554.36*
	Interval deviant after attentive condition								
Aural	510.15	515.08	515.38	513.85	515.08	514.92	514.62	514.77	516.77
Non-aural	573.64**	575.64**	573.45**	575.64**	574.36**	572.73**	572.91**	570.91**	570.73**

T(22)= † p<.05, * p<.01, ** p<.001

Learning effects for MMN latencies were explored similarly as for amplitudes (Figure 7). The aural group had significantly shorter Interval-MMN after attentive condition than before (p<.03 for all electrodes except 12 that had p=.06), whereas non-aural group had significantly longer Interval-MMN latencies than before the attentive condition (p<.02 for all electrodes).

Correlation to AMMA test. A significant correlation was found between the AMMA test (especially with the Rhythm subtest) and the Contour-MMN (in the transposed melody paradigm). Table 3 illustrates the significant correlations for all participants. No significant correlations were found between Interval-MMN or Optimal paradigm deviants and the AMMA test. Results mean that enhanced MMN for Contour related to more accurate performance in the AMMA test.

Table. 3.
Pearson correlation coefficients between AMMA test and Contour MMN

	Contour deviant before attentive condition								
	Frontal electrodes			Frontocentral electrodes			Parietal electrodes		
AMMA	5	6	7	11	12	13	17	18	19
Tonal	-0.27	-0.30	-0.30	-0.37	-0.33	-0.43	-0.36	-0.25	-0.30
Rhythm	-0.41*	-0.44*	-0.39	-0.41*	-0.39	-0.45*	-0.36	-0.34	-0.36
Total	-0.35	-0.39	-0.36	-0.39	-0.36	-0.45	-0.36	-0.28	-0.31
	Contour deviant after attentive condition								
Tonal	-0.25	-0.31	-0.44*	-0.37	-0.43*	-0.45*	-0.46*	-0.45*	-0.32
Rhythm	-0.37	-0.44*	-0.53**	-0.43*	-0.50*	-0.53**	-0.45*	-0.49*	-0.38
Total	-0.31	-0.39	-0.50*	-0.40	-0.49*	-0.51*	-0.44*	-0.48*	-0.36

* p<.05, ** p<.01

Attentive condition in the transposed-melody paradigm

In the EEG recordings, there was a short (12 minutes) attentive condition between the two ignore conditions. Due to small number of deviant trials, only the behavioral performance was analyzed from this condition.

There were no differences between groups in the Grier's A (Grier 1971) non-parametric detection scores (indexing the response sensitivity), percentage of hit rates and false alarms (wrong button presses) or reaction times for either of the deviants. Both deviants were detected equally and well above the chance by both groups (mean false rate for Contour deviant was 15% and for Interval deviant 14%) and performance between deviants correlated significantly (for Grier's A, r=.76, p<.001). This implies that the participants detecting the Contour deviant accurately, detected also the Interval deviant well.

Grier's A for both deviants correlated significantly with the Contour-MMN amplitudes before the attentive condition (see Table 4). This implies that the larger the MMN amplitude was before the attentive condition, the more accurate the behavioral discrimination. According to participants' feedback the discrimination task was quite demanding.

Table. 4.
Pearson correlation coefficients between Grier's A (for the Contour and Interval deviant) and Contour MMN

Grier's A for	Contour deviant before attentive condition								
	Frontal electrodes			Frontocentral electrodes			Parietal electrodes		
	5	6	7	11	12	13	17	18	19
Contour	-0.28	-0.43*	-0.38	-0.37	-0.47*	0.33	-0.39	-0.46*	-0.41*
Interval	-0.32	-0.43*	-0.43*	-0.46*	-0.55**	-0.43*	-0.49*	-0.49*	-0.46*
	Contour deviant after attentive condition								
Contour	-0.22	-0.13	-0.04	-0.25	-0.16	-0.11	-0.21	-0.20	-0.10
Interval	-0.16	-0.15	-0.04	-0.27	-0.14	-0.13	-0.15	-0.14	-0.03

* p<.05, ** p<.01

Discussion

This study aimed at exploring whether there are differences in preattentive and attentive sound processing between musicians preferring aural or non-aural practicing and performing strategies. Aural performing strategies consisted of improvising, playing by ear and rehearsing playing by listening to recordings. Traditionally musicians participating to neuroplasticity studies have been classical musicians or musicians playing various genres of music but grouped into a single experimental group. However, according to preliminary findings, the neural processing may differ according to which performing strategy musicians prefer (Tervaniemi et al. 2001).

A musical background questionnaire especially designed for the study was used to explore strategy profiles between aural and non-aural groups, including preferences for learning, practicing activities and strategies. According to the results, there were differences at the neural and the behavioral processing between aural and non-aural groups. Furthermore, in both groups neural processing differed between isolated sound features (in paradigm adopted from Näätänen et al. 2004) and sound patterns (in paradigm modified from Tervaniemi et al. 2001). The differences between groups are interpreted as related to learning strategies and performance practice experience. Next, the findings are discussed according to the research problems and some theoretical implications are provided.

1. Do musicians differ according to whether they prefer using of aural or non-aural strategies? The present results indicate that musicians can be classified according to their self-reported preferences to employ aural strategies, such as improvising, playing by ear and rehearsing by listening recordings. The aural group was defined as employing distinctly more of the aural strategies. These strategies are typical in pop and jazz training, where musical scores provide only a clue about what the music might be. Hence, it was not surprising that more pop and jazz musicians reported to prefer aural strategies. However, there were also classical musicians in the aural group as well as pop and jazz musicians in the non-aural group. Chronological age, the amount of practicing and study years did not differ between groups. Many of the practicing and memorizing related strategies did not differ between groups but composing was more employed by the aural group.

In general, the aural group had a more diverse set of self-directed rehearsal strategies whereas the non-aural group had more formally learned skills. For example, the non-aural group had more music theory studies than the aural group. Although the questionnaire provided valuable explanatory information of all musicians, it included questions that were oriented mainly for classical style musicians and not for pop and jazz musicians. The reliability of the data could be improved by piloting the questionnaire with several types of musicians.

2. Does preattentive neural sound processing for sound features differ between musicians preferring aural strategies vs. non-aural strategies? Overall, preattentive neural processing of most sound features, such as frequency, intensity, sound omission and spatial location does not seem to differentiate musicians preferring aural or non-aural strategies. The MMN topography to the various sound features were similar than in previous studies (Näätänen & Tiitinen 1998). The largest MMN peaks were located frontally for all the deviants except the Location, for which the MMN was maximal at the posterior area. Also the MMNs to all the deviants except Gap one were lateralized to the right hemisphere.

However, there were differences between MMN latencies and the amplitudes evoked by different sound feature deviants. The Location and Frequency were processed significantly faster than the Duration, Gap or Intensity deviants. The MMN to the Duration deviant was stronger that for the other deviants. This result is similar to Näätänen et al. (2004) study results in which the Duration had the largest and the Gap the smallest MMN amplitude.

3. Does the preattentive processing and learning after attentive discrimination of complex sound patterns differ between musicians preferring aural vs. non-aural strategies?

There were also group differences in the transposed-melody paradigm MMN data. Interestingly, the Contour-MMN was enhanced in amplitude when compared to the Interval-MMN. This suggests that processing may differ depending on the tone pattern Gestalt: the Contour deviant was a more salient Gestalt than the Interval deviant. This result is similar to Trainor et al.'s (2002) finding of an earlier MMN to the Contour than to the Interval deviant within melodies. According to them the faster processing of the melody contour may result from the use of short-term memory and abstract-pattern matching that enhances the processing with contours. However, recent study showed that musicians had larger MMNm for the Interval than for the Contour deviant (Fujioka et al. 2004). Interval deviant (transposed 5-tone patterns with raised last tone) in their study reminds, though, both deviants used in the transposed-melody paradigm while the Contour deviants are not as comparable. Differences in the physical parameters cannot explain the saliency of the Contour deviant because the frequency changes between standard and deviant were actually smaller with the Contour deviant than with the Interval deviant. Previous studies have shown that the larger the physical difference in the deviant when compared to standard, the larger is the MMN (e.g. Tervaniemi et al. 2005). According to this study, the MMN may vary according to the Gestalt (or 'melodic form' in this case) of the abstract sound pattern. Previous studies have showed that MMN occurs for the abstract relations between sounds or conjunction rules between physical sound features (i.e., "the higher the frequency, the higher the intensity" as in Paavilainen et al. 2001 study). In addition to this kind of abstract rules, results from this study suggest that also the form of the melodic tone sequence might affect the MMN in musicians.

The results do not support the previous findings in which the MMN was larger immediately after the attentive discrimination task (e.g. Näätänen et al. 1993, Tervaniemi et al. 2001, Gottselig et al. 2004). Learning effects in this study were investigated by comparing the MMN amplitudes in an ignore condition following an attentive discrimination-training condition to a first baseline ignore condition. According to the present results, the MMN to the Interval deviant was significantly smaller after the attentive condition with the aural group while there were no changes between conditions with the Contour deviant MMN for either of the groups.

So far, there are no studies showing a decreased MMN or other ERP indices of learning in auditory modality immediately after short-term attentive training. Also the repetition priming studies indicating faster responses (i.e., repetition priming) and a decrease of the cortical activity may not apply in the case of oddball paradigm where deviant occurs randomly and rarely among regularly repeated standard stimuli (see, e.g. Bergerbest, Ghahremani & Gabrieli 2004 for the reduced BOLD response in the auditory cortex). Hence, repetition priming (and decreased cortical activity) might well apply only to the processing of the standard stimuli. Thus, further studies should explore the development of the standard stimuli activity as compared to the development of the MMN. Also, in order to study learning effects, the long lasting experimental blocks (35 minutes in this study) should be divided into shorter analyzing blocks. Hence, the temporal evolution of the learning effects would be revealed. In this study the possible immediate (within 10-20 minutes) increasing of the MMN and decreasing after repetition and habituation could not be explored.

One explanation for the differences between previous studies and the current result might the biases caused by different participant backgrounds and musical experiences. Unfortunately, in Tervaniemi et al. (2001) study, no strict definition of which kind of improvising musicians (reported to be superior in automatic pitch-change detection within complex patterns), nor any statistical evidence of their superiority when compared to other musicians were provided. Moreover, in Tervaniemi et al. (2001) only one deviant sound pattern was used, while in this study there were two deviant patterns. This might have increased the discrimination difficulty of this paradigm. The difficulty of the complex sound patterns affected the MMN in Gottselig et al. (2004) study where learning effects (MMN grew after attentive condition) occurred only to the easiest sound patterns. The difficulty of the deviants would explain why there were no significant learning effects, as indexed by an enhanced MMN, in the present study. A third bias might lie in the experimental instruction which was kept non-directive, i.e., participants were not told that there were two deviants. This might have deteriorated the performance of many participants, because the attentive discrimination task was considered quite demanding according to oral feedback from participants. In future studies, the amount of practice of the participants and their instruction should be systematically varied to determine the moderating effects of such factors known to of fundamental importance for learning.

Yet, taken together, the results suggest that there might be a limit in complex sound processing even among professionally studying musicians. These findings encourage one to further study what are the limits of learning at both preattentive and attentive levels in experts and whether there are differences in the learning rate between experts in the same field. The effects of individual differences in educational backgrounds (including strategy and practice preferences) in the field of expertise and the instructions given in the measurements should be considered carefully.

4. Are there behavioral and/or neural differences among musicians preferring aural vs. non-aural strategies? Advanced Measures of Musical Audiation (AMMA) test scores were significantly different between the aural and the non-aural groups. The non-aural group was significantly better in tasks relating to pitch changes (in Tonal subtest) and had higher total score for the AMMA test than the aural group. The result is in contrast with the assumptions made by Gordon (1989) according to whom audiation skills are the next stage after improvising and playing by ear. This raises a question what audiation really means. One possible explanation for the superiority of the non-aural group is that the musicians belonging to this group had significantly more music theory and ear training studies. Maybe the AMMA performance benefited of formally learned analytical skills. This interpretation suggests that also the amount of theory studies in music should be balanced when comparing different musicians for example by controlling which theory courses they have and how much they employ those in their daily work.

The AMMA rhythm subtest did not differ between groups. An interesting result was that the Rhythm subtest related significantly to the age of starting to play in band or orchestra. This suggests that musical experience may have an impact to the perception of the rhythmic stimuli. However, subtests were strongly intercorrelated which indicate general accuracy in both of the Tonal and Rhythm tasks. The variation between participants in all AMMA scores was enormous (over 50 points) in both groups although all participants were studying music at professional level. Part of the variation may be explained by motivational or attentional bias during the experimental session. Alternatively, the variation may refer to the fact that variables such as motivation, deliberate practice, and support may explain music study success, as has been found by Lotti (1987) and Sloboda (1985). Although the AMMA test provides norms for musician students, the use of AMMA for comparing musicians should be considered critically as large variation among musicians, like that shown in this study, might occur. A suggestion to reliably use the AMMA test could be to following up individual’s own progression in musical skills (as is suggested in the AMMA manual).

Furthermore, the results answered positively to the question concerning relations between behavioral measures and preattentive sound processing. It was found that musicians who had higher AMMA scores (especially the Rhythm part) had enhanced Contour-MMN (transposed-melody that changed the second last tone of the contour) after the attentive condition while no connection was found with the Interval-MMN (transposed-melody changing the last tone with a quint interval). These results support the previous findings of Tervaniemi et al. (1997) and Lang et al. (1990) that high performance in musicality test relates to enhanced MMN. Difference in these studies is the fact that stimuli used in AMMA tests and in EEG were not alike (although both were melody patterns) in this study while previous studies used matched stimuli in the EEG and musicality test. Also, aforementioned studies did not separate the effects of rhythmical or tonal items to MMN.

Another significant correlation was found between the MMN amplitude to the Contour deviant and the attentive discrimination accuracy during the transposed-melody paradigm: initially (before the attentive condition) a larger MMN to the Contour deviant related to better behavioral performance in the attentive discrimination task. This finding is similar to previous finding (Gottselig et al. 2004). It seems that initial preattentive detection facilitates the attentive discrimination accuracy of similar stimuli. Still, this may not be enough to produce enhanced preattentive processing after attentive discrimination (i.e., a learning effect) at least when stimuli are complex.

Summary

According to the present findings, both behavioral and neural processing differences do exist between different kinds of experts of the same professional field and expertise level, such as the musicians participating to this study. Musicians' preferences and strategies in practice and learning might depend on the musical experience and the demands in particular professional area. The present study explored the effects of musicians' long-term practice for auditory sensory memory. Differences in the preattentive neural sound processing as indexed by mismatch negativity (MMN) for isolated sound features was found to be quite similar between musicians who prefer improvising, playing by ear and rehearsing by listening recordings ('aural group') and with musicians who do not ('non-aural group'). Also the attentive discrimination of complex sound patterns (so-called transposed-melodies) did not differ between groups. However, there were group differences in the MMN amplitude and latency when comparing the learning effects for the complex sound patterns. While the non-aural group had no learning effects in amplitudes for either Contour deviant (in which the melody contour was changed by second last tone) or Interval deviant (in which the last tone was changed by a quint), for the aural group the MMN for the Interval deviant diminished after attentive task. Both groups had stronger Contour-MMN than Interval-MMN after attentive task suggesting the difference between the preattentive processing of different sound patterns. Also, the initial MMN for the Contour deviant correlated to the behavioral discrimination accuracy in the attentive task. The Interval-MMN latencies showed a contradictory pattern: non-aural had slower Interval-MMN than aural group already before attentive task and it got longer after attentive task while in the aural group the Interval-MMN latency got shorter after attentive task. These findings are in contrast to previous studies indicating an enhanced MMN after attentive behavioral discrimination task and require further studying by varying the difficulty of the stimuli, the used instructions, attentive conditions and the time period for the experiment. The present findings suggest that attentive discrimination might not be sufficient for learning effects to occur even in professionally oriented musicians when auditory stimuli are very complex or when attentive training is short.

There were group differences also in the behavioral level. It was found out that non-aural group had higher AMMA scores for Tonal subtest and for the whole test. This result cannot be explained by the age of commencement of playing, main instruments, practice hours per week, musical working experience, or study year in the current school because these did not differ between groups. However, it was found that non-aural group had more formal music theory studies. Rhythm subtest did not differ significantly between groups but in contrast to assumption that previous practice does not affect musicality test performance, it was found that the Rhythm subtest related significantly to the age of commencement in band or orchestra playing. Similarly to previous findings of relations between musicality test performance and neural processing, AMMA test (and especially the Rhythm subtest) related significantly to Contour-MMN before and after attentive condition. These findings might indicate that musicality tests (or parts of those) are not totally independent of experience and/or practice.

In summary, present findings suggest that practice strategies might affect preattentive neural and attentive behavioral processing in musicians. However, results give only partial support for the learning effects after attentive discrimination task in musicians with the complex sound patterns. The results encourage further investigation of the limits of learning and the factors behind possible differences in the learning between experts in the same field.

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Appendix 1: Questionnaire for Musicians

Dear Participant

This is a questionnaire for finding out more your musical background and playing. Please answer carefully to each question. If some question does not include suitable answering options you may write further comments to some of the open text boxes in the questionnaire. Questionnaire is confidential. Your questionnaire will be combined to other research information about you by means of the first letters of your names you'll give in the first question. After this all data about you is handled in a unidentified way. It will be made sure also that there is no possibility to identify anyone from the research report.

This study is part of the research done in the Cognitive Brain Research Unit and Master's Thesis project in the Department of Psychology in the University of Helsinki. You may send your comments and further suggestions about the questions by email to miia.seppanen@helsinki.fi . Also you may ask further information about this study by email.

Notice that some questions allow to select only one option and some questions allow several options to be selected. Some questions include open text boxes where you can write text. If any of the options are not suitable you may skip that question and write your comments to some of the open text boxes if needed. After you have answered to all questions, click *Send my data* button in the end of the questionnaire. Do not use enter button in any phase of answering but use instead a mouse or tabulator key in the keyboard.

Thank You for participating!

Basic information

1. Initials of your first name and surname
2. Sex
3. Age
4. Are right-handed / left-handed
5. Your email where you want the research report to be sent
6. Do you have a diagnosed dyslexia (reading and writing learning disorder)? (no/yes/I don't know)

Studying and vocational information

(Fill all the sections if necessary, for example if you are already graduated from one school and continuing in another school).

7. Student
    a. School (Sibelius-Akatemia, other, what:
    b. Study program (soloist musician/ instrument teacher (in Finnish: soitonopettaja), accompanist, singer, church musicians, music teacher at (primary/secondary) school, other, what:
    c. How many years you have studied in this school?
8. Graduated

(continues)

   a. Name of the degree (musiikkialan perustutkinto, Musiikin kandidaatin tutkinto (Bachelor of Music), Musiikin maisterin tutkinto (Master of Music), Musiikin lisensiaatin tutkinto (Licenciate of Music), Other, what:
   b. Detailed name of the degree
   c. School
   d. Graduation year
9. Working, occupational title (or description of the work)
   a. Soloist musician, instrument: , instrument teacher, instrument:, orchestral musician, musician in a pop/light music band, accompanist, instrument, singer, church musician, music teacher at (primary/secondary) school, other, what:
   b. At what age did you start to play professionally?
10. Have you had any breaks in full-time playing?
    a. Yes
       i. How long the break was?
       ii. How old were you during the break?
    b. No

Questions about Your main instrument

11. Your main instrument:
    a. At what age did you start to take music lessons with the main instrument?
    b. How many hours do you practise the main instrument in one week?
    c. Latest exam for the main instrument:
       i. Other exam, what:
    d. At what age you made the latest exam for the main instrument?

Questions about Your secondary instrument

(OBS! You may skip question 12 sections if you don't take music lessons for any secondary instruments)

12. Your secondary instrument(s):
    a. At what age did you start to take music lessons with the secondary instrument(s)?
    b. How many hours do you practise the secondary instrument(s) in one week?
    c. Latest exam for the secondary instrument(s):
       i. Other exam, what:
    d. At what age you made the latest exam for the secondary instrument(s)?
    e. Do you think that playing secondary instrument(s) has been useful for You in playing main instrument?
       i. Yes, how: / No / I don’t know

Questions about playing

13. When do you start playing a piece without score?
    a. After couple of playing times/after month of playing, after several months, only for performance, never
14. What kind of aids you use for memorising musical pieces?
15. Describe in general terms what your practise sessions typically includes
    a. Name here some musical pieces that are included to your current repertoire:
16. How much do you practise playing mentally (in your mind by imagery)?
    a. Never (move on to the next question 17), 10 % / 30% / 50% / 80 % of practising time / always

(continues)

    b. If you can, please evaluate how many hours per week you practise playing mentally
    c. If you use mental practising, what kind of mental images you typically use?
    d. How much do you think mental practising improves playing?
        i. A lot / quite a lot / quite a little / a little
17. How much do you practise by reading the notes?
    a. Never / 10 % / 30% / 50% / 80 % of practising time / always
18. How much do you practise by listening the music piece recorded (either your own playing or other musician's playing)?
    a. Never, 10 % / 30% / 50% / 80 % of practising time / always
19. Do you use metronome when you practise?
    a. No / yes, occasionally / yes, regularly
20. Do you play music outside of your current repertoire?
    a. No / yes, a little / yes, a lot
21. How often you play music by ear (finnish: korvakuulolta)?
    a. Never / seldom / quite seldom / quite often / often
22. Do you play by scores when performing at the stage as a solist?
    a. Never, 10 % / 30% / 50% / 80 % of performances / always
    b. How many times do you perform in one year? (give a closest estimation)
23. Do you improvise?
    a. No (move on the next question 24)
    b. Yes
        i. Which instrument?
        ii. How often do you improvise (several times a day / once a day / once a week / less freguently)
    c. how you would like to improvise *preferably*?
        i. According to some theme / according to some spontaneous idea, other:
    d. Do you improvise *usually*
        i. together with other musicians / alone
    e. What kind of music do you improvise?
    f. What is the level of difficulty for the improvised music you play *usually*
        i. same level as my current repertoire
        ii. easier level than my current repertoire
24. How many hours per week do you compose music?
25. Do you accompany freely (in Finnish: vapaasäestys)
    a. no (move on to the next question 26)
    b. yes
        i. which instrument
        ii. How many hours per week do you accompany freely?
        iii. what kind of music you accompany freely?
        iv. what is the level of difficulty for your freely accompanied music *usually(*same level as my current repertoire / easier level than my current repertoire)
26. Do you participate in choir, band or orchestra
    a. no (move on to next question 27)
    b. yes (you may choose several options)
        i. I sing in the choir
            1. at which age you started to sing in the choir?
            2. how many hours per *week* you participate to the choir
        ii. I play with others in a band or in an orchestra
            1. which instrument
            2. at which age you started to play in a band or orchestra?

(continues)

        3. how many hours per *week* do you participate to the band or orchestra?

27. Primavista playing
    a. Have you completed a primavista course?
        i. Yes, which grade did you have
        ii. No
    b. Do you think that primavista is (easy / quite easy / quite difficult / difficult)
    c. in what way primavista is easy or difficult in your opinion?
    d. what is the level of difficulty for your primavista usually? (same level as my current repertoire / easier level than my current repertoire)
    e. What kind of strategies do you use when playing primavista (for example when you prepare to play, during your play etc.)?
    f. What kind of pieces you would like play as primavista?
28. About ear training
    a. Do you have absolute pitch? (yes / no / I don't know)
    b. How you would evaluate your relative pitch (that is ability to discriminate certain pitch related to other pitches)? (good / quite good / quite bad / bad / I don't know)
    c. Last ear training course you participated (säveltapailu, solfa-kurssi)?
    d. Grade from the lates ear training course?
    e. Was there any difference between the grades from rhythm and melody tasks?
        i. Rhythm was better than melody / melody was better than rhythm / both equally good / I don't know
    f. What kind of strategies do you use in melody dictation and rhythm tasks?
29. Music Theory
    a. Have you studied music analysis?
        i. No
        ii. Yes
            1. how many years:
            2. what is the last course you have completed?
    b. Have you studied counterpoint or 'satsioppi'?
        i. No
        ii. Yes
            1. how many years:
            2. what is the last course you have completed?
    c. Figured bass ('kenraalibasso')
        i. Have you completed the figured bass course (both writing and playing)?
            1. no / yes / yes, I have participated but not completed
        ii. What kind of strategies do you use when playing figured bass?

Other musical background

30. How many music (instrument) teachers you have had?
    a. Describe your typical music (instrument) lesson (what methods teacher used, how she/he guided your development etc.)
31. Own preferences
    a. What kind of music you like? (you may choose several options)
        i. Light music, traditional dance music / rock / pop, new dance music / jazz / folk music / classic / spiritual, religious music / children music / other, what:
    b. How many hours do you listen recorded music per week?
        i. 0 hours / 0-3 hours / 3-6 hours / 6-9 hours / over 9 hours
    c. To what factors in music you draw attention?

(continues)

d. What makes the music good in your opinion?
e. Are you familiar with non-western music cultures? (you may choose several)
    i. Asian / African / Latin / other, what:
f. Do you participate regularly to rhythmic exercise (for example dance, music aerobic etc.)?
    i. Yes / no

32. Childhood
    a. Have you been in the musical playschool (musiikkileikkikoulu) or other structured musical activity before going to first grade to school? (yes / no)
    b. Have you been in the music class (musiikkiluokka) in the school? (you may choose several)
        i. 1-6 grades (or lower elementary school)
        ii. 7-9 grades (or upper elementary school)
        iii. upper secondary school
    c. Are there others in your family who play some instrument?
        i. mother is a professional musician
        ii. father is a professional musician
        iii. some of the siblings are professional musicians
        iv. some of the siblings or parents take music lessons or play instrument but are not professional musicians
        v. nobody else plays any instrument
    d. How much music was listened in your childhood home?
        i. Daily / weekly / less frequently
    e. What kind of music was listened in you childhood home? (you may choose several options)
        i. Light music, traditional dance music / rock / pop, new dance music / jazz / folk music / classic / spiritual, religious music / children music / other, what:
    f. How many different instruments you have played altogether in the childhood?
    g. Musical memories from your childhood (for example did you sing a lot as a child, did you invent musical pieces etc.)

Thank You for Participating!

Note. Few items were excluded from the statistical analysis because of missing values and the ambiguous nature of some of the questions according to the few participants' judgment. An example of ambiguous items is the question: "When do you start to play without scores". Participants commented that to this question they could answer differently depending on the musical piece and whether they liked it or not. Another ambiguous question was: "How many times do you perform per year?" In this case, participants said that they did not know whether the performing could mean accompanying someone else, playing with others, or playing solo. Despite of these difficult items, most of the questions produced interpretable answers. Open-ended questions were categorized by gathering occurring themes and combining the similar themes into one category. Some of the open-ended questions were analyzed only descriptively because the answers were too much dispersed (could not be categorized into salient themes) or too alike, or there were too few answers.

Appendix 2: Information consent form

This study is part of Pro gradu project of Miia Seppänen in the University of Helsinki, Deparment of Psychology. The researcher responsible for this study is docent Mari Tervaniemi. Study is made in the Cognitive Brain Research Unit of the University of Helsinki.

Study has two parts: 1) EEG registering that takes about 3-4 hours with the preparations, 2) two listening experiments and a background questionnaire that takes about 1 hour. The subject grant will be paid after the part two. The reward is 6 euros per hour, so altogether you will get 30 euros (minus taxes) from being a subject.

A special EEG cap is used in EEG measurement. This is connected to the head with water-soluble electrode paste. Sticker electrodes are put to the face and behind the ears. After measurement you can will have a towel and you can use the shower in order to you're your hair with the shampoo.

During EEG registering

- You will sit comfortably in the chair and look a movie that you can select yourself
- There are 5 sections: a) 15 min movie, b) 24 min movie, c) 12 min a task to follow sounds and push the button, d) 24 min movie and e) 12 min movie.
- There will be breaks between the sections and tea/coffee and biscuits can be served.
- Please sit as still as you can, avoid unnecessary moves and body tension. These distract the measurement. All the scratches and changes of your position should be postponed until the break comes (between the sections). Take easy but not too easy!
- When looking the movie do not pay attention to the sounds you may hear but concentrate only to the movie.

Please use the toilet before the measurement if necessary. If you use eyeclasses, bring your classes with you. Do not use contact lens during the experiment.

You can ask freely about the study during experiments. You participation is voluntary and you may discontinue if you need to. All the results are handled anonymously and no subject can be identified from the result raports. You may have the Master's thesis when it's ready (at the spring 2005). This is a non-profit study project.

You are welcome to the Cognitive Brain Research unit and to this brain study. Share your experience in the interesting field of research - how musicians' brains work.

☐ I am informed about this study and my rights as a subject

☐ I shall participate to the study voluntarily

Date / 2004 Signature

Name

Appendix 3: EEG instructions

This study includes 5 sections. Try to sit as still as you can because every head and body movements distract the EEG registering. **Do not close your eyes and try not to move during the measurement.** I shall close this door always when the measurement starts. I shall open it every time the measurement ends and we will take as long break as you need. You can move during the breaks. I can make coffee or tee and bring biscuits in some of the breaks.

- First section takes 15 minutes. You may hear sound but concentrate only to the movie.
- Second section takes 24 minutes. Again there may be sounds but you don't need to pay attention to those. Concentrate only to the movie.
- Third section takes 12 minutes. This time you will not look at the movie. I give you a button box. Your task is to hear sounds. If you hear some deviant among the sounds push the button 1. Fixate your eyes to one point.
- Fourth section takes 24 minutes. You may continue looking the movie. Do not care about the sounds.
- Fifth (the last) section takes 12 minutes. You may continue looking the movie. Do not care about the sounds.