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Electroencephalographic gamma-band activity and music perception in musicians and non-musicians

Yuko Urakami [1], Koki Kawamura [2,3], Yoshikazu Washizawa [3,4], Andrzej Cichocki [3]

[1] Hospital and Research Institute, National Rehabilitation Center for Persons with Disabilities, Tokorozawa, Japan; [2] Department of Anatomy, School of Medicine, Keio University, Tokyo, Japan; [3] RIKEN Brain Science Institute, Laboratory for Advanced Brain Signal Processing, Wako-shi, Japan; [4] Department of Communication Engineering and Informatics, University of Electro-Communications, Tokyo, Japan.

Correspondence to: Yuko Urakami, MD., PhD., 4-1 Namiki, Tokorozawa-city, Saitama. Japan.
TEL. +81.42.995.3100 (7102); FAX: +81.42.995.0355; E-MAIL: urakami-yuko@rehab.go.jp

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Abstract

BACKGROUND: Music perception involves acoustic tone activity, melody, harmony analysis, and processing of musical syntax and semantics that may activate the prefrontal cortex. Musical training has structural and functional effects on the brain. The purpose of this study is to evaluate neural mechanisms during music listening and imaging in musicians and non-musicians.

METHODS: Spontaneous brain activity was measured in 6 musicians and 5 non-musicians while listening to 2 pieces of classical music (Symphony No. 9 in E minor [From the New World] by Antonín Dvořák; “Dies Irae” from Requiem in D minor by Wolfgang Amadeus Mozart) (2.5 min each) and imaging both pieces (1 min each). Electroencephalography was performed using a 60-channel electrode cap. Morlet wavelet time-frequency analysis was performed and root mean square was calculated for each frequency band.

RESULTS: During music listening, gamma activity (30 to 50 Hz) was significantly decreased in all regions, especially the prefrontal cortex. During music imaging, gamma activity was significantly decreased in the entire brain in musicians, but was increased in the frontal lobe in non-musicians.

CONCLUSIONS: Musicians have significantly lower frontal gamma activity during music listening and music imaging than resting state, possibly due to a trained ability to integrate implicit memory from acoustic memory and direct inner consciousness toward self-reference and attention. Music influences human cognition and emotion, and plasticity associated with musical training may be measured.

Introduction

Music has appeared throughout human history, and the first *Homo sapiens* probably made music 100,000 to 200,000 years ago (Koelsch 2011). Humans are unique in that they learn to play musical instruments and they make music cooperatively in groups. The musical abilities of humans are important in the evaluation and processing of language (Wallin *et al* 2000), music making promotes important social functions such as communication, cooperation, and social cohesion (Koelsch 2011).

Music is a valuable tool for the understanding of human cognition, emotion, and brain mechanisms (Altenmüller 2008). Music perception begins with acoustic information that is decoded, translated into neural activity in the cochlea, and transformed in the auditory brainstem. The dorsal cochlear nucleus projects to the reticular formation and the inferior colliculi may initiate flight and defensive behavior in response to threatening stimuli, even before acoustic information reaches the auditory cortex. Neural impulses are transmitted from the thalamus to the auditory cortex, amygdala, and medial orbito-frontal cortex (Kaas *et al* 1999). Neural impulses reach the auditory cortex via subdivisions of the medial geniculate body into the primary auditory cortex (Brodmann area 41) and adjacent secondary auditory fields (Brodmann areas 42 and 51). Auditory features are extracted, the acoustic information enters the auditory sensory memory (echoic memory), and representations of auditory gestalten are formed (Griffiths & Wallen 2004). Operations of the auditory sensory memory are partly reflected electrically in mis-match negativity (Näätänen *et al* 2001).

The auditory system includes the dorsal and ventral pathways from the posterior association area to the prefrontal cortex, being analogous to the visual system. Cognitive information conveyed from the posterior association cortex extends to the prefrontal cortex from the parietal and temporal lobes. The prefrontal cortex that contains Broca area, and the posterior association area that contains Wernicke area, are interconnected with association fibers. In the dorsal pathway, projections from the posterior association area to the prefrontal cortex can be used to program action. The ventral parts of the frontal lobe and the temporal pole are interconnected, and both have reciprocal connections with the amygdala; impulses through these 2 routes are integrated to process a behavioral response (Kawamura 2012). Brain functions may include emotional activities in the limbic system including the cingulate cortex, hippocampus, orbital cortex, amygdala, and nucleus accumbens.

The professional musician acquires performance skills after many years of intensive training. These skills are among the most complex human abilities and involve several different brain regions (Peretz 2006). Professional musical training can change the functional and structural organization of the brain and provides an opportunity to study neuroplasticity (Münte *et al* 2002).

Neurophysiologic studies using electroencephalography (EEG) and magneto-encephalography have shown that oscillatory gamma activity may be important for neuronal processing (Tallon-Baudry & Bertrand 1999; Fries *et al* 2007; Jensen *et al* 2007). Synchronized gamma may occur in different cortical areas. Human gamma activity is associated with cognition and may be a coherent cortical representation of complex external sensory stimuli. Oscillatory gamma activity associated with attention and memory during complex cognitive processes such as attention, motor planning, working memory, and long-term memory in both sensory and non-sensory areas (Tallon-Baudry & Bertrand 1999; Gruber *et al* 2004; Kaiser *et al* 2004; Hoogenboom *et al* 2006; Jensen *et al* 2007; Van der Werf *et al* 2008). Musical training has a strong effect on the degree of induced phase synchrony in the gamma frequency range during music processing but not during text processing (Bhattacharya & Petsche 2001). Musicians may have an increase in the degree of phase synchrony in the gamma frequency range.

Resting state networks are spontaneous, low-frequency oscillations observed in the brains of subjects who are awake and at rest. The default mode network is a specific, anatomically-defined brain system that is preferentially active when individuals are not focused on the external environment, and the default mode network may be important for understanding mental disorders including autism, schizophrenia, and Alzheimer disease (Buckner *et al* 2007). Mindfulness meditation training causes changes in default mode network activity that may be measured in the gamma range and may result from an increase in attention skills and awareness to internal and external sensory stimuli (Berkovich-Ohana *et al* 2012). Similar patterns of default mode network connectivity occur in subjects who are listening to music in an introspective manner (Kay *et al* 2012). The imaging of previously heard music requires memory integration and inner self-attention.

The purpose of the present study was first to evaluate the temporo-spatial neural networks that are active during music listening and music imaging, and to determine the measurable changes in resting state networks in EEG that are associated with default mode network activity within the gamma frequency range. Second, to clarify the differences of gamma activity between musicians and non-musicians whether if gamma activity may be associated with musical listening and imaging experiences.

Methods

Participants

Participants of this study were 6 musicians (age, 21 to 25 y; 4 men and 2 women) and 5 healthy non-musicians who had not received any professional musical training (age, 21 to 24y; 4 men and 1 woman).The musicians included 5 students at the University of Music (specialty: percussion, 3 students; singing, 2 students [baritone]) and 1 professional singer (soprano) and had professional music training >5 years. The non-musicians were general university students who were studying mathematics (2 students), agriculture (1 student), or economics (2 students). None of the subjects had any neurologic or hearing deficit or were using pharmaceutical drugs. All subjects were right-hand dominant (Edinburgh inventory) (Oldfield 1971). The purpose and details of the research were explained to the subjects, and informed consent was obtained. This study was approved by the Ethical Committee of the National Rehabilitation Center for Persons with Disabilities.

Study design and procedure

The study was performed with a condition-dependent change design. Participants sat in a dim experimental room that was shielded from external noise, and they listened to music from bilateral earphones with the eyes closed and in a relaxed condition. Spontaneous EEG was recorded during 3 conditions (1) resting state with eyes closed for 1 minute, (2) listening to music for 2.5 minutes, and (3) imaging the music without listening for 1 minute. These 3 conditions were repeated in all subjects with 2 pieces of classical music: (1) Music 1was from the second movement (Largo, D-flat major, "Going Home") of Symphony No. 9 in E minor (From the New World, Op. 95, B. 178) by Antonín Dvořák; and (2) Music 2 was the sequence "Dies Irae" from Requiem in D minor (K. 626) by Wolfgang Amadeus Mozart. Music 1 was selected because it is known to many people. Music 2 was selected because it is very strong and impressive with most people. The name of the music was not provided before the experiment.

Electroencephalography

The EEG recordings were performed with a 60-channel electrode cap (Elekta-Neuromag, Stockholm, Sweden) placed on the scalp according to the international 10-10 system, sampled at 1001 Hz, and referenced to linked earlobe electrodes (A1 and A2) (Reilly 2005). The impedance of all electrodes was <20kΩ.

A 50-Hz band-stop filter was applied to remove ham noise; a 50-Hz low-pass filter was applied to the signals; and the signals were resampled at 125.1 Hz. A 0.1-Hz high-pass filter was applied to remove signal drift.

The condition of the subject was observed from outside the shielded room with a video camera that was mounted inside the room. During the recording, the measured EEG signals were observed on a monitor located outside the shielded room. The EEG signals with the eyes closed were selected for analysis, and the epochs including motion artifact, blinks, horizontal-vertical eye movements, and muscle artifacts were excluded by visual inspection.

Morlet wavelet time-frequency analysis was performed, and the root mean square (RMS) (measured in μV) spectral distribution was calculated for each frequency band: delta (0.1 to ≤3.5 Hz), theta (3.5 to ≤7.5 Hz), alpha (7.5 to ≤13 Hz), beta (13 to ≤ 30 Hz) and gamma (30 to ≤50 Hz). The 60 electrodes were organized into 9 regions of interest: left and right frontal, left and right central, left and right parieto-occipital, left and right temporal, and midline regions (Figure 1).

We removed electromyographic activity from scalp and neck muscles, or saccade-related spike potentials due to eye movements (Hassler *et al* 2011; Keren *et al* 2010; Plöchl *et al* 2012; Muthukumaraswamy 2013). We carefully visually inspected the raw data, manually extracting artifact-free epochs. Artifact from muscle potential was removed for each subject and channel by removing the signals for 1 s when the instantaneous voltage was 3 times > standard deviation or > 100 μV. As the EMG peaks at 70–80 Hz, we used much lower frequencies, in the 30–50Hz. The RMS was obtained for each condition and averaged, in each frequency band, and subject. Average values of RMS of musicians and non-musicians were plotted in topographic maps.

Statistical analysis

Data were reported as mean ± standard deviation. Comparisons of mean RMS between participant groups (musicians and non-musicians) and conditions (resting, music listening, and music imaging) were performed with 1-sided t test and analysis of variance. Statistical significance was defined by $p \leq 0.05$.

Results

The 6 musicians all previously knew Music 1 and Music 2, and 2 musicians had performed Music 1 in concerts. The 5 non-musicians all previously knew or had heard Music 1 but did not know the title of the music, and 3 non-musicians had not previously heard Music 2.

In all subjects combined (musicians and non-musicians), the mean RMS during listening to Music1 and Music 2 decreased most markedly in gamma-band than other activity (Table 1 and Figure 2). Gamma-band activity in the midline, which constituted the default mode network, significantly decreased during music listening (Figure 3). Beta-band activity significantly

Tab. 1. Root mean square electroencephalographic activity during music listening or imaging compared with resting state in musicians and non-musicians.

Band (Frequency)	Music 1				Music 2			
	Music Listening	*p*≤†	Music Imaging	*p*≤†	Music Listening	*p*≤†	Music Imaging	*p*≤†
Delta (0.1 to 3.5 Hz)	97±8	NS	93±8	0.009	100±6	NS	100±10	NS
Theta (3.5 to 7.5 Hz)	103±8	NS	94±6	0.005	100±8	NS	97±10	NS
Alpha (7.5 to 13 Hz)	98±15	NS	89±8	0.001	97±18	NS	92±16	NS
Beta (13 to 30 Hz)	93±6	0.01	90±9	0.003	93±9	0.02	92±9	0.008
Gamma (30 to 50 Hz)	90±7	0.001	94±14	NS	92±7	0.002	96±13	NS

N=11 subjects (6 musicians and 5 non-musicians). Data reported as rate of root mean square (RMS) (mean ± SD) (units) for all participants combined. RMS rate >100, increase; RMS rate <100, decrease compared with resting. †Comparison of music listening or imaging vs resting state. NS, not significant (p>0.05)

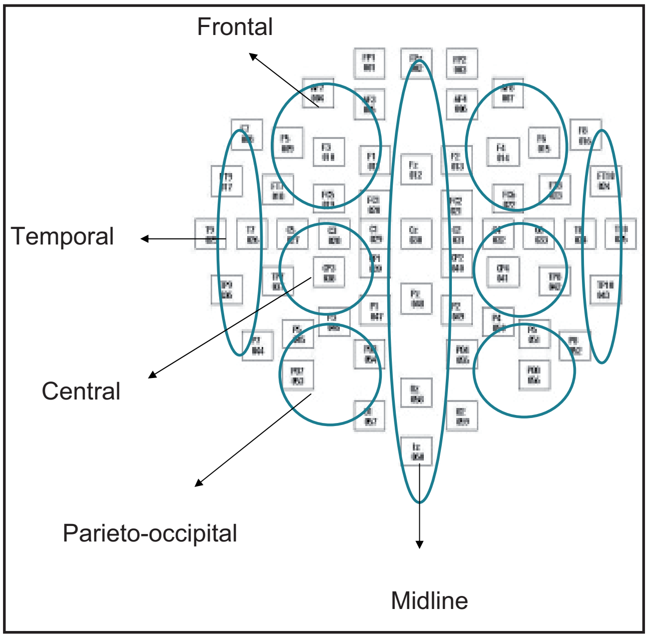

Fig. 1. Electroencephalographic electrode positions and regions of interest for evaluation of brain activity with resting, music listening, and music imaging. There were 60 electrodes organized in 9 regions of interest: left and right frontal, left and right central, left and right parieto-occipital, left and right temporal, and midline regions.

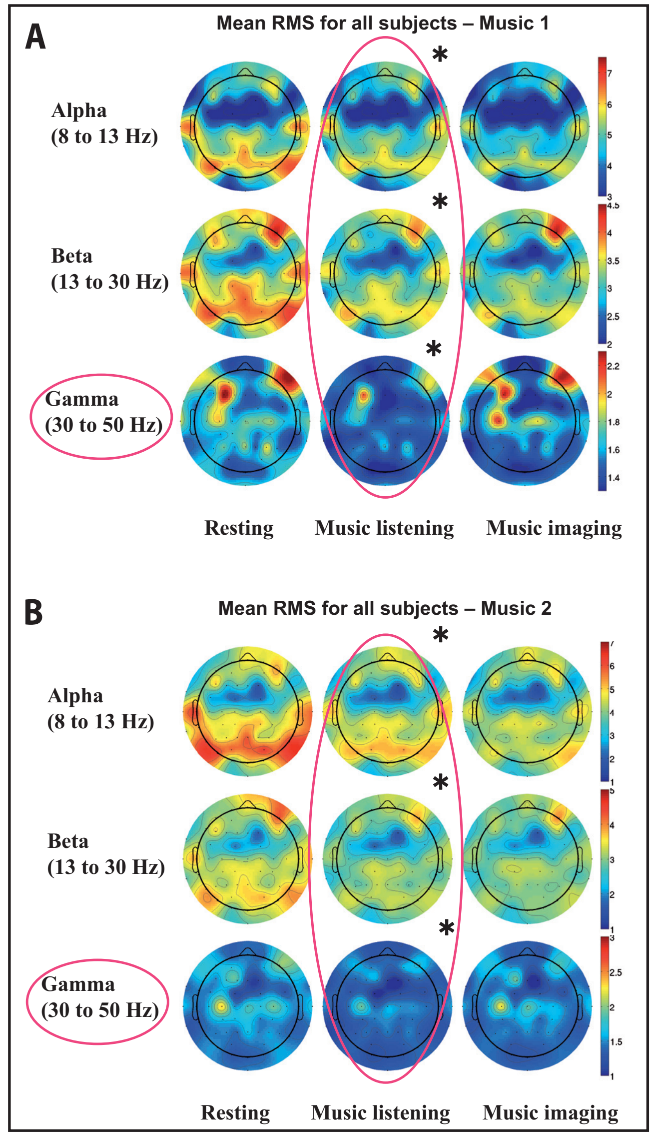

Fig. 2. Electroencephalography during resting, music listening, and music imaging in musicians and non-musicians combined. Mean root mean square is noted by the color scale (μV). (A) Music 1. (B) Music 2 (*$p \leq 0.05$).

decreased during music listening and music imaging, especially in musicians during listening to Music1 (Table 1). Theta-band and alpha-band activity significant decreased during music imaging of Music 1 but not Music 2 (Table 1).

For Music 1, musicians had significant decreases in mean RMS activity in the whole brain for gamma-band activity (listening and imaging), beta-band activity (listening and imaging), and alpha-band activity (imaging but not listening) (Table 2). For Music 1, non-musicians had only few areas with significant decreases in RMS activity for gamma-band activity (listening, 2 regions), beta-band activity (listening, 4 regions), and alpha-band activity (imaging, 4 regions) (Table 2).

For Music 2, musicians had only few areas with significant decreases in mean RMS activity for gamma-band activity (listening, 4 regions; imaging, 3 regions), beta-band activity (listening, 3 regions; imaging, 3 regions), and alpha-band activity (listening, 1 region; imaging, 1 region) (Table 2). For Music 2, non-musicians had some areas with significant decreases in mean RMS activity for gamma-band activity (listening, 5 regions) but few areas with significant decreases in beta-band activity (listening, 4 regions; imaging, 3 regions) and alpha-band activity (listening, 1 region; imaging, 3 regions) (Table 2).

Analysis of variance showed that the musicians had significantly lower mean rate of RMS activity than non-musicians during resting, music listening, and music imaging in the gamma-band activity at the left frontal lobe during Music 1 ($p \leq 0.05$) (Figure 4) and right frontal lobe during Music 2 ($p \leq 0.05$). On the contrary, non musicians significantly increased during imaging the music than resting and music imaging. There were no other differences in mean rate of RMS activity between musicians and non-musicians during resting, music listening, and music imaging in gamma-band activity at the other EEG regions or in theta-band, alpha-band, or beta-band activity in all 9 regions.

Discussion

In the present study, the most prominent feature of the EEG activity is the decrease of gamma activity in the whole brain in musicians during music listening and imaging for Music 1 (Table 2). In addition, musicians

Tab. 2. Root mean square of gamma, beta, and alpha activity for musicians and non-musicians during music listening and music imaging compared with resting state.

Band (Frequency)	Region	Music 1				Music 2			
		Musicians		Non-musicians		Musicians		Non-musicians	
		Music Listening	Music Imaging	Music Listening	Music Imaging	Music Listening	Music Imaging	Music Listening	Music Imaging
Gamma (30 to 50 Hz)									
	No. regions decreased	8	8	2	0	4	3	5	0
	Frontal, left	0.002	0.003	NS	NS	NS	NS	NS	NS
	Frontal, right	0.006	0.02	NS	NS	0.05	NS	NS	NS
	Central, left	0.006	0.009	NS	NS	NS	NS	NS	NS
	Central, right	0.003	0.01	0.009	NS	NS	NS	0.04	NS
	Parieto-occipital, left	NS	NS	NS	NS	0.002	NS	0.02	NS
	Parieto-occipital, right	0.006	0.02	NS	NS	NS	0.03	0.04	NS
	Temporal, left	0.001	0.003	0.05	NS	0.01	0.05	0.02	NS
	Temporal, right	0.001	0.003	NS	NS	NS	NS	NS	NS
	Midline	0.007	0.01	NS	NS	0.004	0.05	0.03	NS
Beta (13 to 30 Hz)									
	No. regions decreased	8	9	4	0	3	3	4	3
	Frontal, left	0.006	0.001	0.009	NS	NS	NS	0.05	NS
	Frontal, right	0.009	0.002	0.008	NS	NS	NS	NS	NS
	Central, left	0.03	0.004	NS	NS	0.02	NS	NS	NS
	Central, right	0.03	0.000x	NS	NS	NS	NS	0.04	0.05
	Parieto-occipital, left	0.05	0.001	NS	NS	0.002	0.02	0.004	0.004
	Parieto-occipital, right	NS	0.02	0.04	NS	NS	0.009	0.01	0.007
	Temporal, left	0.001	0.000x	0.03	NS	0.01	NS	NS	NS
	Temporal, right	0.001	0.001	NS	NS	NS	NS	NS	NS
	Midline	0.03	0.002	NS	NS	NS	0.05	NS	NS
Alpha (7.5 to 13 Hz)									
	No. regions decreased	1	9	0	4	1	1	1	3
	Frontal, left	0.01	0.009	NS	NS	NS	NS	NS	NS
	Frontal, right	NS	0.03	NS	0.05	NS	NS	NS	NS
	Central, left	NS	0.007	NS	0.03	NS	NS	NS	NS
	Central, right	NS	0.003	NS	0.03	NS	NS	NS	NS
	Parieto-occipital, left	NS	0.003	NS	0.03	0.02	0.04	NS	0.02
	Parieto-occipital, right	NS	0.02	NS	NS	NS	NS	0.05	0.03
	Temporal, left	NS	0.04	NS	NS	NS	NS	NS	NS
	Temporal, right	NS	0.007	NS	NS	NS	NS	NS	0.03
	Midline	NS	0.02	NS	NS	NS	NS	NS	NS

N=6 musicians and 5 non-musicians. Data reported as number of regions with decreased root mean square activity compared with resting activity; significant P value; or not significant (NS, $p>0.05$).

had significantly less activity than non-musicians in the frontal lobe in gamma activity during resting, music listening, and music imaging. Musicians had significantly decreased frontal gamma activity for Music 1 during music listening and imaging than resting (Table 2), possibly because their ability to integrate implicit memory that occurred from acoustic memory and direct inner consciousness pertaining to self-reference and attention. Non-musicians had increased mean frontal gamma activity during music imaging (Figure 4), which

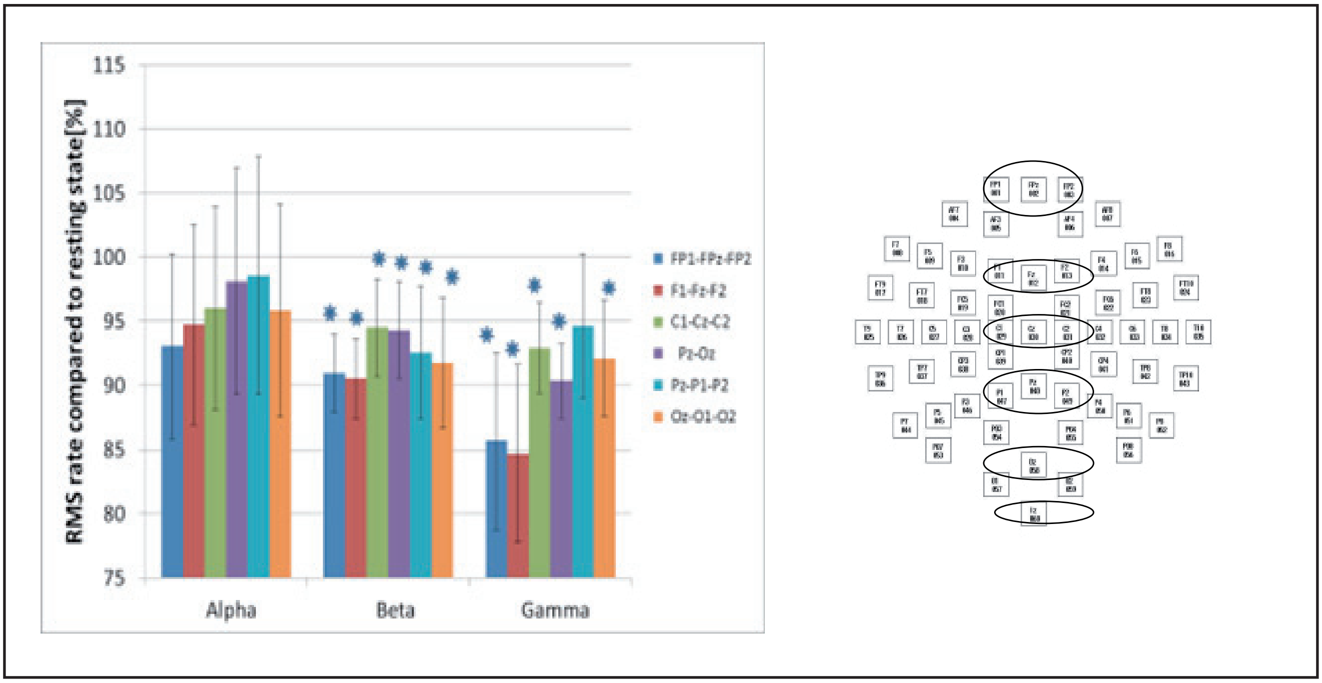

Fig. 3. Electroencephalography in the midline during music listening compared with resting in musicians and non-musicians combined. Mean rate of root mean square (RMS) during listening is shown normalized to the resting value (data for delta and theta waves not shown). Gamma activity in the midline was the default mode network. Abbreviations: FP1 or FP2, frontal pole or prefrontal; FPz, midprefrontal; F1 or F2, frontal; Fz, frontal midline; C1 or C2, centrotemporal; Cz, central midline; Pz-Oz, parieto-occipital; P1 or P2, parietal-posterior temporal; Pz, parietal midline; O1 or O2, occipital; Oz, occipital midline (**p*≤0.05).

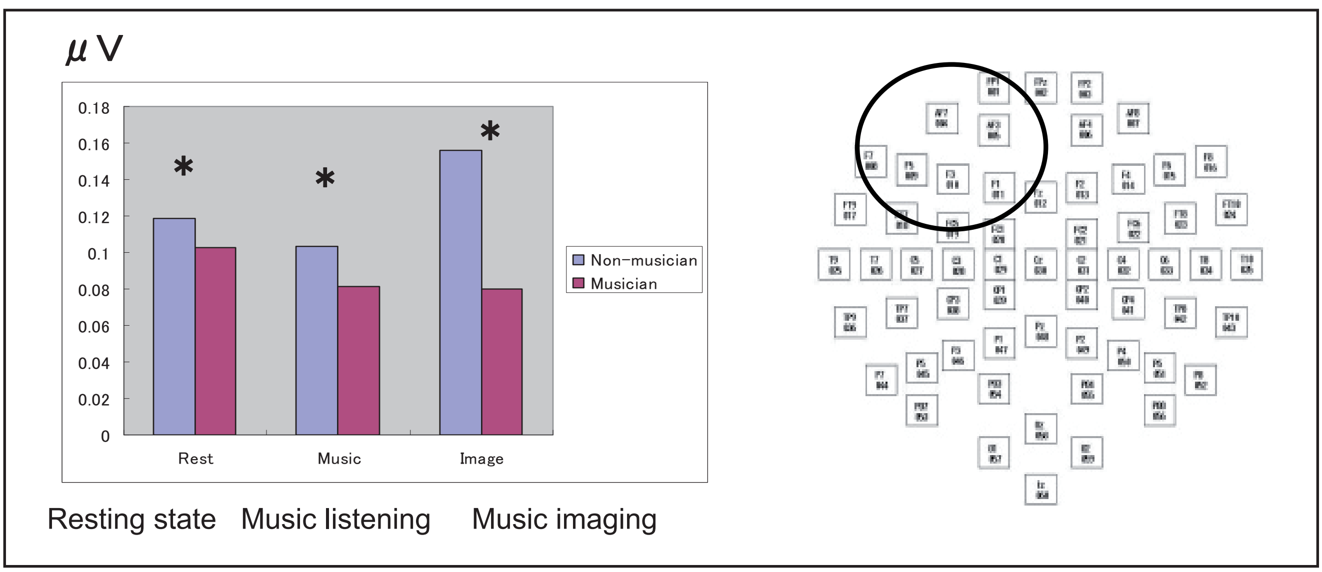

Fig. 4. Electroencephalographic gamma-band activity in the left frontal lobe for music 1 in musicians and non-musicians. The mean rate of root mean square activity was significantly less for musicians than non-musicians in resting, music listening, and music imaging and was significantly greater for non-musicians during music imaging than resting (**p*≤0.05).

is a different skill than music listening. Non-musicians imaged the music as an attention condition to the external stimuli. Although the brain responses differed to the different types of music (Table 2), EEG gamma activity was a measure of cognitive processing during music listening. The changes in gamma activity during music listening, especially in the frontal lobe, suggest that the anterior frontal lobe, including the prefrontal cortex, insula, and Broca area, are important in music perception.

Music is an unique auditory stimulus in studying human cognition, emotion, behavior, and the neural elements involved in processing sound (Koelsch 2011). Functional neuroimaging studies represent neural structural and functional correlates and show a close relation between the neural processing of music and language syntactically and semantically. Broca area, a region traditionally considered to subserve language, is important in interpreting whether a musical note is on or off key. The frontal operculum is associated with musical syntax, and the superior temporal sulcus is used in sound processing for many purposes including the possible semantic interpretation of music and linkage of this interpretation to non-musical constructs.

The music used in this research was selected because Music 1 was a nostalgic melody that had a very slow rhythm, and Music 2 was an impressive chorus melody that had a faster rhythm. During music listening, both music selections induced decreased gamma and beta activity in musicians; otherwise, the activity patterns frequently were different between listening and imaging and between the 2 music selections (Table 2). Therefore, different rhythms and melodies may affect brain oscillation differently.

Fast cortical oscillatory activity in the gamma-frequency band (30–100 Hz), as recorded in humans using EEG or magnetoencephalography, has considered being associated with various cognitive functions, in attention and both working and long-term memory (Jensen *et al* 2007). The default mode network includes frontal and midline structures, and EEG gamma activity in the frontal and midline channels is a marker of default mode network activity (Gusnard & Raichle 2001; Buckner *et al* 2008). The default mode network is distinct from most task-specific networks, and the brain may increasingly recruit with decreasing external task demands, especially at the medial prefrontal cortex, hippocampal formation, posterior cingulate cortex, precuneus region, and temporo-parietal junction. Default network recruitment occurs with internally focused thought that may occur with mind wandering, mindful meditation, or music listening (Wegner 1997; Gusnard & Raichle 2001; Raichle *et al* 2001; Smallwood & Schooler 2006; Mason *et al* 2007; Kirschner *et al* 2012).

Music listening is a state of passive task performance in the default mode network. Music listening requires sustained attention to external stimuli, and the increase in attentional skills and heightened awareness to internal and external sensory stimuli.

During mind wandering, when attention is focused internally, neural phase synchronization in high-density EEG occurs between regions associated with the default network (Kirschner *et al* 2012). When subjects are focused on performing a visual task, more neural phase synchrony occurs within task-specific brain networks. These differences in network synchrony may occur with theta, alpha, and gamma activity, and oscillatory synchronization is a potential mechanism for functional coupling within task-specific and default networks. However, it is unknown how the brain switches functionally between task-specific and default networks, and whether these networks are always negatively correlated or can be stimulated simultaneously.

Behavioral evidence for an implicit memory system is based on experiments in which experience causes altered performance on a task without subjects being aware of having learned anything. Implicit memory is acquired knowledge that is not available to conscious access (Schacter 1987). In contrast, explicit memory is characterized by knowledge that involves conscious recollection, recall, or recognition. Implicit memory for music includes priming, which is an implicit memory effect in which exposure to a stimulus influences responses to a later stimulus without awareness or recall of the specific stimulus. Music may be a human universal activity, present in all cultures (Blacking 1973; Zatorre & Peretz 2001). The ability to perform music skillfully is not evenly distributed in people and may require extensive formal training; however, the ability to listen, process, and respond emotionally to music is shared between most people and may depend only on implicit memory.

Implicit memory is important in the acquisition of rhythm, pitch, and melodic structure (Krumhansl 1990). The significantly decreased gamma activity in musicians during music listening (Table 2) may have occurred, musicians listened with exclusive attention to the music in a highly trained condition, and they recalled the known music with an implicit memory and a comfortable state of inner self consciousness, analogous to meditation.

Musical production involves motor areas in conjunction with other functional systems such as somatosensory, auditory, visual, emotional, and memory loops. Musicians may have a higher intensity of intrinsic activity in these multisensory and motor systems than non-musicians. Synaptic plasticity in single neurons may facilitate networks of neurons to encode and represent memory, and this plasticity may be necessary and sufficient for information storage in the brain (Neves *et al* 2008). Training can change the functional and structural organization of the brain and the functional changes of the adult hippocampus in humans related to musical training are suggested (Herdener *et al* 2010). Although brain networks are connected structurally; they may be only transiently connected functionally and efficiently in musicians.

Mental imagination of sounds elicits an increase in alpha-band activity (Palva & Palva 2007). Studies of perception and imagery of music processing show that imagery may increase the strength of alpha activation. Music listening may increase the amplitude of alpha activity and may produce a more introspective pattern of connectivity (Kay *et al* 2012). When comforting music is self-selected, the comfortable condition induces increased alpha activity. In contrast with the results of Kay et al, the present results showed significant decrease in alpha activity only during imaging. Alpha oscillations are considered to strengthen by internal tasks such as mental calculation and imagination. A positive correlation of the alpha amplitude with the short-term memory and working memory load and task difficulty is reported. In addition, the amplitude of alpha activity increases during the short term, and working memory retention inhibits the retrieval of memorized items and suppresses alpha amplitude. The decrease in alpha activity during music imaging in the present study may reflect retrieval-associated alpha suppression (Klimesch *et al* 2006).

We have limited our techniques to those that are commonly used in the examination of music-listening. Due to narrow scope and the limitations of our study, our findings should further be discussed in the future with respect to the broader implications.

In summary, the present study showed that gamma activity decreases during music – listening, especially in the anterior part of frontal lobe. The decreased frontal gamma activity observed in musicians is evidence of highly integrated consciousness, and musicians imaged and replayed the music in the implicit memory that was compiled from the explicit acoustic memory. Music affects human cognition and emotion, and its effect may be measured by gamma activity in EEG. The differences during music perception between musicians and non-musicians may have occurred because of differences in musical training, experiences, and expert skills. These results suggest that musical training may modify many aspects of brain functions including the auditory systems. Neuroplasticity associated with musical training may interfere with premotor functions related to action planning. In addition, making music is an activity that involves social functions including contact with other individuals, social cognition, and communication, coordination of movements, cooperation, and increased social cohesion of a group. Musical experience may modify many brain functions, emotion, cognition, and social functions. Future studies may evaluate training, education, and rehabilitation to improve the potential for learning and plasticity of the human brain.

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