Neural Correlates of Boredom in Music Perception

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ABSTRACT

Introduction: Music can elicit powerful emotional responses, the neural correlates of which have not been properly understood. An important aspect about the quality of any musical piece is its ability to elicit a sense of excitement in the listeners. In this study, we investigated the neural correlates of boredom evoked by music in human subjects.

Methods: We used EEG recording in nine subjects while they were listening to total number of 10 short-length (83 sec) musical pieces with various boredom indices. Subjects evaluated boringness of musical pieces while their EEG was recording.

Results: Using short time Fourier analysis, we found that beta 2 rhythm was (16-20 Hz) significantly lower whenever the subjects rated the music as boring in comparison to non-boring.

Discussion: The results demonstrate that the music modulates neural activity of various parts of the brain and can be measured using EEG.

1. Introduction

Music and its effect on human perception has been a mystery for centuries. While serving different roles in human evolution and development, societies from every part of the world have produced and performed highly diverse music, in addition, the richness of general cognitive mechanisms involved in these musical activities makes them ideal sources of investigation so early in cognitive science (Pearce & Rohrmeier, 2012).

An important part of any musical piece is its ability to modulate the audience's mood, and evoke powerful emotional responses. Increasing the magnitude of this emotional response can lead to higher sense of enjoyment from the musical piece. This emotional excitement can lead to increase in intelligence (Schellenberg, 2005), better psychological mood (Särkämö et al., 2008), and reduction in depression and anxiety (Castillo-Pérez, Gómez-Pérez, Velasco, Pérez-Campos, & Mayoral, 2010; Mok & Wong, 2003; Salamon, Bernstein, Kim, Kim, & Stefano, 2003). Thus, maximizing the emotional enjoyment from a musical piece is not only important for musicians aiming to improve the influence of their composition and performance, but also can have important clinical implications. Furthermore, any Human-computer interface (HCI) can benefit significantly from modulation of the emotional state of the user.

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Brain imaging techniques make it possible to attain particularly useful information about the implied emotional and cognitive contents of a musical piece directly. Neural correlates of pleasant and unpleasant feelings have been studied using electroencephalography (EEG) (Field et al., 1997; Schmidt & Trainor, 2001), positron emission tomography (PET) (Blood, Zatorre, Bermudez, & Evans, 1999; Blood & Zatorre, 2001), and functional magnetic resonance imaging (fMRI) (Koelsch, Fritz, Cramon, Müller & Friederici, 2006). Combination of these techniques (fMRI and EEG) have shown further correlations between responses of pleasant and unpleasant musical emotions (Flores-Gutiérrez et al., 2007). These studies demonstrate the possibility of differentiating neural correlates of generic pleasant and unpleasant feelings.

EEG has several important characteristics that make it ideal to record such correlations between neural and emotional responses. EEG can be recorded in any location in natural body conditions, whereas techniques such as fMRI can only be recorded in specific locations, with the addition of evoked emotions from claustrophobia and scanner noise. Other techniques such as PET face similar problems with the addition of hazards from radioactive materials. Furthermore, recording EEG signals is extremely low cost in comparison to fMRI and PET and can be performed using minimal instruments. In recent years, the commercial costs of EEG systems that can be used without specific knowledge of EEG by the user have been reduced. Additionally, due to the high temporal resolution of EEG, it is possible to study brain processes at various time scales and frequency bands. The activity in these frequency bands can be easily correlated with mental functions and evoked emotions (Mantini, Perrucci, Del Gratta, Romani, & Corbetta, 2007).

Studies using the EEG recordings while listening to music, have shown a decrease in alpha and theta power well defined in the temporal area of the left hemisphere, in comparison with resting state (Petsche, Linder, Rappelsberger, & Gruber, 1988), a decrease in alpha and an increase in theta total power in comparison with listening to nonmusical sounds (Ramos & Corsi-Cabrera, 1989; Yuan, Liu, Li, Wang, & Liu, 2000). Moreover, the pleasant music compared to unpleasant music has been shown to be positively associated with total theta (Kabuto, Kageyama, & Nitta, 1993), and frontal midline theta (Sammler, Grigutsch, Fritz & Koelsch, 2007a) power changes.

However, while emotional excitement from a piece of music is extremely important, the neural correlates of sense of boredom have been poorly understood. Boredom has been subject of various definitions by psychodynamic, existential, arousal and cognitive theories. Generally, it is described as an unpleasant state in which one desires to engage in a satisfying activity but this would be not possible whether because of individual or environmental impairments (Eastwood, Frischen, Fenske & Smilek, 2012). In this study we employed the term boredom in a manner consistent with this definition. Besides, the meaning of boredom is interestingly connected to attention; they are not identical but they have been shown to be closely correlated (Eastwood et al., 2012).

Dorso-Lateral Prefrontal Cortex (DLPFC) area has been demonstrated to be involved in numerous studies of attention deficit hyperactivity disorder (ADHD) (Burgess et al., 2010; Passarotti, Sweeney, & Pavuluri, 2010), drug craving (Fregni et al., 2008; Wilson, Sayette & Fiez, 2004) and obsessive-compulsive disorder (OCD) (Atmaca, 2013; Russell et al., 2003). Therefore, we suggest that this region might be important in modulation of boredom as well as attention, and we should see similar brain indices for them here. However, even though DLPFC has been shown to be extremely important in many cognitive tasks, to our knowledge, its importance in music perception has not been studied using EEG so far. In this study, we examined the changes of brain rhythms including theta, alpha, and beta (low, mid and high) from EEG in this region in response to music pieces.

In this study, we employed EEG to investigate the neural correlates of subjective sense of boredom provoked by music. Several pieces of music that were pre-rated by a group of subjects as boring or non-boring were employed. Most of the boring pieces contained a specific repetitive melodic phrase. These melodic phrases were repeated continuously thorough the pieces with or without variation in every cycle. Conversely, the non-boring pieces were chosen from exciting music compositions. During the EEG session, human subjects were instructed to respond whenever they felt the pieces were boring. The pieces, which were not reported by subjects as boring, were employed as controls. The frequency responses of the EEG recordings were analyzed using Fourier transform. We analyzed the power spectrum of responses in each frequency band.

2. Methods

2.1. Subjects

Nine healthy subjects with the age range of 22 to 30 (5 Male, Six right-handed, Mean age=26.7 ± 2.5) participated voluntarily in this study. The sample size was estimated using PASS 13 (NCSS, LLC) software, with actual power of 0.8 (Liu and Wu, 2005). Case selection was based on available cases. All subjects signed an IRB approved informed consent form, which was provided by ethic board of ICSS (Iran Institute of Cognitive Science Studies). Subjects were unaware to the purpose of the experiment and none had any formal music trainings. All subjects had normal auditory sensitivity. All experimental procedures adhered to the Declaration of Helsinki.

2.2. Auditory Stimuli

Two groups of musical trials were employed in the experiments. Musical pieces were pre-rated between 0 and 10 by 20 subjects that were not involved in the main experiments. The boring group contained eight musical pieces, and non-boring group contained two musical pieces. The subjects participating in the main experiment were not aware that a given piece was pre-rated as boring or non-boring. The period of each trial was 83 seconds.

The boring pieces were specifically composed to contain repetitive melodies in order to become boring in the short period of stimulus presentation. Six of the boring pieces contained a specific melodic phrase, which was repeated continuously thorough each piece with or without variation in every cycle. Three partial examples of boring pieces that contained repetitive melodies are shown in Figure 1 A, C. The average number of repetitive melodic cycles within all the boring pieces, which hold repetitive melodic phrases, was 30.8 ± 15.5. These pieces were sufficiently different to explore a large range of possible boredom sensations. The other two boring pieces were significantly different; one was a fairly long and sustained single note played by a cello, and the other consisted of random musical events to induce boredom with minimum repetitive elements. These two pieces did not contain specific repetitive melodies. Two non-boring pieces were also employed. One was the first movement of an orchestral piece by Igor Stravinsky (Requiem Canticles, 1966) and the other was a segment of a piece composed for piano by one of the authors (AFT - Uncompleted Romantic Piece, 2011). All the pieces but the Stravinsky's "requiem canticles" were computer mock-ups and were composed by Notion 3 software (Notion Music, Inc, Florida, U.S.A). Furthermore, all of the pieces were edited via logic pro 9 (Apple, USA) to succeed equal length, equal volume level, and were finally exported to 16-bit wave files. All pieces are accessible as online materials.

A
B
C

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Figure 1. Three representative samples of repetitive melodic phrases within three boring pieces with 42 (a), 16 (b) and 21 (c) repetitions.

2.3. Experimental Procedures

The final 10 music segments were arranged to be presented consecutively with 30 sec inter-block intervals (Figure 2). Subjects were instructed to sit comfortably in a chair in a silent room, listen to music carefully with their eyes closed, and respond by button press, whenever they judged a musical piece as boring. However, they were also instructed to continue listening until the musical piece was finished. The subject were asked to open their eyes within the silent inter-block interval, respond whether they were familiar with the piece or not, and close their eyes again to become prepared for the next trial. During the EEG recording, the task was presented for the subjects using "eevoke" 3.1 software (ANT Neuro, Netherlands) via active noise-canceling headphones (Audio-technica, ATH-ANC7b) at a comfortable volume. The non-boring pieces were played as the third and seventh trials, each trial was presented once with the same order for all of the subjects and the times refer to as times of boringness were recorded. None of the subjects reported any familiarity with the pieces within each trial.

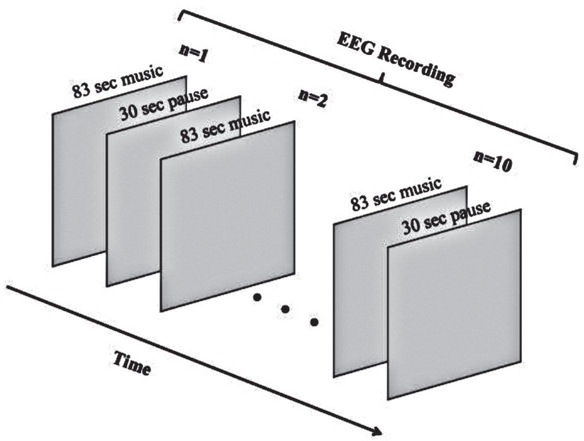

Figure 2. Time course of the EEG recordings. Each musical piece was played for 83 sec followed by a blank 30-sec inter-stimulus interval until all 10 musical pieces were presented.

2.4. EEG Recording and Data Analysis

EEG signals were recorded with 32 electrodes (Wave guard cap system, Netherlands) which arranged on the scalp according to standard 10-20 International system. The signals were subsequently amplified (A.N.T. Enschede, Netherlands), and digitalized with the sampling rate of 512 Hz, and stored on a PC via A.S.A 4.7.1 software (ANT Neuro, Netherlands). Then, the data was imported in MATLAB (Mathworks, USA) for subsequent processing. All signal processing and analysis procedures were performed offline using MATLAB and EEGLAB toolbox (Delorme & Makeig, 2004).

The EEG data was filtered with a FIR band-pass filter between 0.5 and 30 Hz, and 50 Hz notch filtering was employed to remove possible artifacts and the power line noise. The baseline noise was removed and a total of 90 EEG data segments (56 boring, 34 non-boring) was extracted from continue EEG each 83 seconds. A threshold limit at 70 µv was employed for detection and removal of eye movement artifacts. The left DLPFC was chosen as the area of interest and FC5 channel which has been shown to be related to this area (Barr et al., 2011) was selected for investigation. This channel has been shown to have maximum power for monitoring attention related EEG indices during auditory and visual tasks (Sangal & Sangal, 2014).

Fourier analysis was used to calculate the amplitude changes in the time domain within specific frequency bands. Theta (4-7 Hz), alpha (7-12 Hz), beta1 (12-16 Hz), beta 2 (16-20 Hz), and beta 3 (20-28 Hz) were selected for subsequent processing. The 83 seconds EEG blocks were split into four equal (33.2 seconds) overlapping (50%) segments, and Fast Fourier Transformation (FFT) using Cooley-Tukey algorithm was performed to compute the absolute power corresponding to different frequency bands on each short segment.

The powers of all four segments related to FC5 channel were used in statistical analysis for comparing the boring and non-boring EEG signals. Additionally, before the main tests, a Shapiro-Wilk test of normality was performed. The data sets were estimated to normal distribution.

3. Results

The results show beta 2 power alterations are notably different between a portion of boring and non-boring pieces of music. Beta 2 rhythms decreased whenever the subjects rated the music as boring and increased when they reported non-boring. The results demonstrate that the emotion evoked by the music, has important correlations with neural activity and can be measured noninvasively. Furthermore, this emotional response might be correlated with changes in EEG.

3.1. Reaction Time

Reaction times (RT) of the selected boring pieces by nine subjects are shown in Figure 3. The dotted line depicts the average reaction time for all subjects. The re-

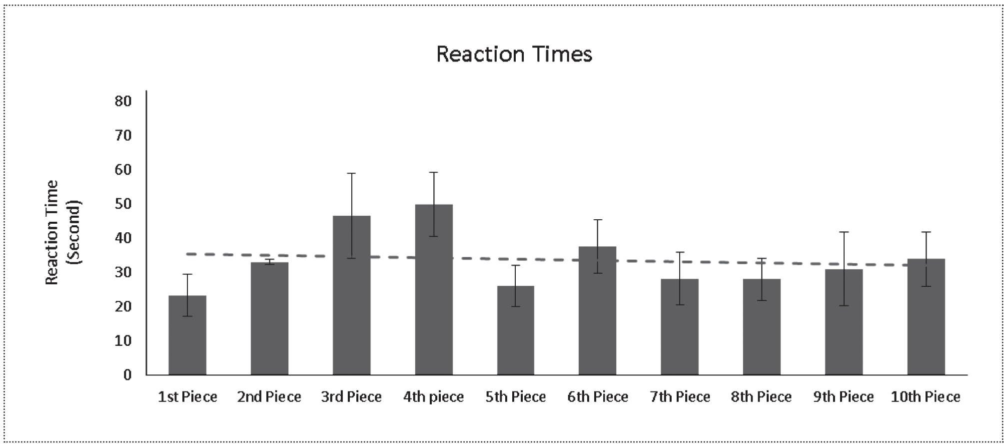

Figure 3. Subjects mean reaction times for all 10 musical pieces, the dotted line depict average reaction time of subjects. NEUROSCIENCE

sponse is often received within 30 to 40 seconds. The numbers of clicks in four windows are as follow: 1st (n=36), 2nd (n=27), 3th (n=12) and 4th (n=3). In the majority of boring pieces, the subjects reported boredom early in the first half of the piece, but not near the end.

3.2. Statistical Analysis

As the number of perceived boring and non-boring pieces were different between the subjects, for each subject, the average power of perceived boring and the average power of perceived non-boring pieces were calculated particularly for each frequency band. Furthermore, listening to boring piece and non-boring piece were defined as the song-type factor (two levels). In other hand, song-segment was also defined as the second factor (four levels). Hence, numbers of five two-way repeated measure analysis of variance (ANOVA) tests were conducted to test whether these two factors have significant effect on measured powers of different spectral bands. These two factors showed to have effect only on beta 2 power:

The two-factor analysis of variance showed no significant main effect for the song-type factor, $F(1,7)=3.3$, $P>.05$; no significant main effect for the song-segment factor, $F(3,21)=1.7$, $P>0.05$; but the interaction between song-type and song-segment was significant, $F(3,21)=3.8$, $P=0.02$. Violations of sphericity were corrected by the Greenhouse- Geiser epsilon correction.

Moreover, in order to determine the simple main effects of song-type factor on the interaction, four paired t-test between boring and non-boring pieces beta 2 power in all four song segments were conducted. The results indicate that the beta 2 mean power for boring (M=898.3, SD=154.7) and non-boring (M=1127.5, SD=274.7) pieces were significantly different ($t(7)=-2.31$, $P=0.04$) only in the first segment.

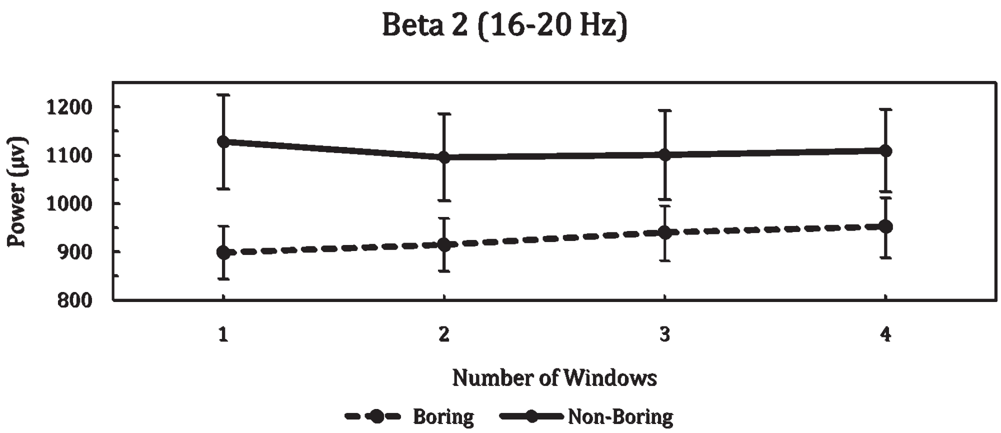

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Figure 4. Changes in beta 2 mean power across different windows. The error bars show the standard errors of the means (SEM).

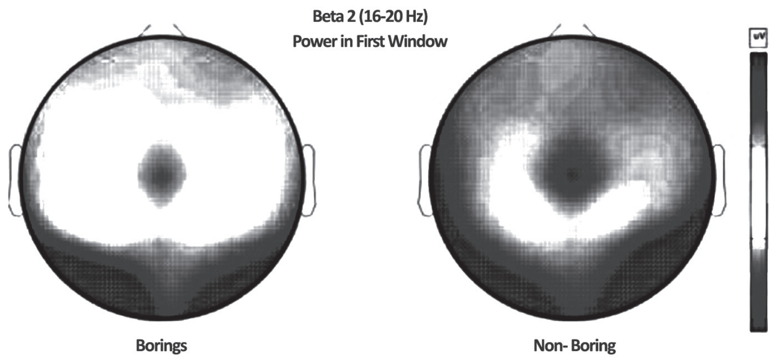

Figure 5. Scalp topographies for boring (left) and non-boring (right) conditions show beta 2 power activity within the first segment of the pieces.

The beta 2 power changes for boring and non-boring pieces in the FC5 electrode are shown in Figure 4. Beta 2 rhythm shows lower power for the boring pieces and higher power for the non-boring pieces during the first segment of the pieces in comparison with the other three segments.

3.3. Scalp Topographies

The scalp topographies of boring and non-boring signals, over beta 2 frequency bands are shown in Figure 5. The mean power of beta 2 band for each channel was calculated and the scalp topographies for boring and non-boring signals were mapped. The maps show different brain activity for the boring and non-boring conditions within the first segment of the pieces. These differences are mostly observed in the left temporal area, but left DLPFC, which is the target region of this study, also shows considerable power difference between two conditions. The FC5, which has been chosen as the proper channel for left DLPFC depicts greater beta 2 power in non-boring condition.

4. Discussion

In this study, we measured associations between evoked sense of boredom and neural recordings from EEG. The left DLPFC region was chosen to be analyzed. Beta 2 mean power was significantly different at the first segment of the boring and non-boring piece.

The RT results suggest the first segment as the most rated one in which the subjects have reported their sense of boredom. Interestingly, the results for the first group analysis have also suggested that only time span wherein the beta 2 mean power between the boring and non-boring pieces was different. So, these results might indicate the beta 2 mean power as a proper brain index for boredom.

4.1. Comparison to Previous Music Emotion Studies

Brain rhythms have been used as a reliable marker for investigating human emotion induced by musical stimuli. In majority of music emotion studies, theta rhythm has been reported to have different features for pleasant and unpleasant music in different part of the brain. For example, in an study, lower theta relative power has been detected during listening to an unpleasant sound comparing to listening to a piece of music as a pleasant sound (Ramos & Corsi-Cabrera, 1989; Yuan et al., 2000). Also pleasant (contrasted to unpleasant) music has been shown to be associated with an increase of frontal midline theta power (Sammler, Grigutsch, Fritz & Koelsch, 2007b) and total theta power (Kabuto et al., 1993). However, in this study, we have also found beta power operating differently between boring and non-boring musical pieces in left DLPFC.

4.2. Relationship to Attention

Boredom is a mental state that is poorly understood and defined differently. Eastwood et al. (2012) defined it as “the aversive state that occurs when we (a) are not able to successfully engage attention with internal (e.g. thoughts and feelings) or external (e.g. environmental stimuli) information required for participating in satisfying activity; (b) are aware of the fact that we are not able to engage attention which can take the form of either awareness of a high degree of mental effort expended in an attempt to engage in the task at hand or awareness of engagement with task-unrelated concerns (e.g. mind wondering); and (c) attribute the cause of our aversive state to the environment (e.g. “this task is boring”, “there is nothing to do”) (Eastwood et al., 2012). Thus, boredom and attention might be closely correlated but boredom might require higher-level processing of attention state. We examined the neural dynamics over left

DLPFC, a region that has shown to be involved in many attention studies to find whether attention and boredom share similar EEG indices.

Beta has been concerned in attention in animals and humans (Basile et al., 2007; Gross et al., 2004; Koshizawa et al., 2013; Wróbel, 2000). Since Beta power has shown to be an indicative of heightened cortical arousal, lower beta power has been shown to be related to lower attention level (Bogart & Pope, 1994). Additionally, ADHD of children who have shown to have sustained attention impairment (Rubia, 2011; Willcutt, Doyle, Nigg, Faraone & Pennington, 2005), display decrease in beta mean frequency (Chabot & Serfontein, 1996; Clarke, Barry, McCarthy & Selikowitz, 1998; Adam, Clarke, Barry, Bond, McCarthy & Selikowitz, 2002; Lazzaro et al., 1998; Mann, Lubar, Zimmerman, Miller & Muenchen, 1992), and this activity reduction is mostly observed in left DLFC (Sangal & Sangal, 2014).

Thus, observed lower beta power over left DLFC in the boring pieces compared to non-boring in this study, could be a sign of lower attention level of the subjects. This is in agreement with Eastwood's definition of boredom in which the subjects are not able to successfully engage attention with environmental stimuli. Moreover, these results could lead to suggest that less attractive components within the boring pieces might not absorb the attention of the subjects, thus, yield a lower attention level in them. Therefore, these finding are consistent with our hypothesis and suggest that boredom and attention share a similar brain index over left DLPFC. Probably, the results of this study could be used clinically as a way for tracking the attention level and boredom state of patient just by a single electrode and music listening. In this study, there was limitation with the task design, as there was no standard boring and non-boring musical pieces in the available data banks, the subjects were responsible to choose whether the music was boring or not, this could add some extra brain activity in comparison with simply just listening to music. Moreover, as there was no sophisticated evidence for the time aspect of sense of boredom in music perception, the length of the musical pieces and the explored epochs was chosen arbitrarily, which both can be calculated via advanced methods for achieving more sensitive results in future studies to overcome the non-stationary nature of the EEG.

In this study, we showed that the emotion evoked by the music can be correlated with neural activity and might be measured by EEG. Our results suggest that the emotional state of boredom might be correlated with lower beta activity in left DLPFC and lower attention level. Furthermore, investigating different parts of the brain can help to add more clarification of boredom and other musically induced emotions.

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