# EEG Spectral Feature Markers as an Indicator of Human Cognitive Process

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**Abstract—**Information technologies allow using modern and timely effective analyses of EEG waves and the methods of data processing that allows effective usage of this method into pedagogically and psychologically oriented research. Aim of this study was to develop and validate method of EEG signal spectral properties usage in the investigations of the process of cognition in the process of the perception of music by the choice of professional studies. 23 research participants took part in the research – the students at the University of Latvia, the division of participants "non-musician" and "musician". The EEG recording synchronized with the musical signal using the generated synchronization signal that given to one of the unipolar input channels of the EEG equipment. The research analyses the basic rhythm of EEG the changes of the maximum frequency and the wave frequency power in the processes connected with the perception and cognition of music for 15 seconds long intervals. During the time of listening to the chorus songs, the range frequency of the range rhythm of alpha and beta does not change to the musicians but during the time of listening to the instrumental music it increases but it was more vivid in the range of beta frequency. Non-musicians reacted differently – while listening to chorus songs and instrumental music the frequency of alfa waves of EEG increased, but the beta wave frequency decreased. EEG as a method of investigation is recommended for pedagogical research to evaluate the neurological functions in the cognitive processes.

**Keywords—**cognition, education, music, neuroscience, power of EEG frequency

## 1 Introduction

Different studies have been carried out on the perception of music in recent years, showing the mechanisms and functions of the brain involved in the processing of signals of a given modality. The interdisciplinary research in neuroscience, psychology, biology, and music pedagogy made it possible to understand brain functions regarding music. These data made a great contribution to modern music education. Results of these studies could be helpful to music educators and musicians for the study and communication about music [1].

Nowadays there has been an increasing number of studies on music perception and performance, and their correlation with processes taking place in the central nervous system. The increase in the number of scientific papers on music is linked to the fact that research into music contributes to a better understanding of the structure and functioning of the human brain [2]. Furthermore, studies have shown that music education helps students to develop learning abilities, improve their academic performance and develop a range of skills and knowledge that are essential for lifelong success [3]. An approach for learning music with the intelligent classroom teaching system has been developed. The teaching system of intelligent classroom has different modules, and this system should have managed by database system, which can help to assist and deepen the teaching and understanding of music [4].

Music plays an integral part in forming the self-identity of adolescents and young people's as well as making their group identity based on their music preferences. Results of neuroscience studies allow producing the developmental model that explain the neural link between adolescents' behaviour and brain development. The musical and social choices are possible to explain based on the research of adolescents during brain development [5]. Learning of music is closely linked to memory and language. Memory functions as interacting systems, which leads to encoding information, storing it, and making it available for retrieval. Nervous system gives ability to acquire different skills and knowledge. Language plays a direct role in human cognition. Language allows to combine meanings by constructing relational units and correlational networks [6]. For acquirement of music important is also mobilization of different human functions to perform various tasks.

Many studies have shown the behavioural peculiarities of musicians and adolescents during music training in processing sounds and speech by changing signal properties (temporal and/or spectral). These effects are often associated with auditory cortex functional and structural changes, but it is oversimplified. However, it is necessary to move from the functions of local brain structures to neural networks and brain oscillatory dynamics [7]. The human brain possibly contains different neuronal networks with specialization for the processing of music. Brain specialization for music depends on the recruitment of "free" neurons and development of their connections during music lessons in the infants and adolescents' brain. Music could modify neurons to suit the processing of certain information, and thus it is associated with the specialization of neurons to perform certain functions. This type of specialization is closely linked to human culture and its impact on cognitive processes. The neural networks that are specific for music correspond to musical capabilities, and they are developing in different people of the same culture. These abilities need to be universal in different cultures and they help to develop musical competence. Depending on the nature of the music, different neuronal networks may be involved in its perception [8].

Over the past decade, much experimental evidence has highlighted the importance of automatically activated neural networks in the auditory cortex in musically significant forms of cognition [9]. The research suggest that the brain produces temporarily individualized neuronal responses to the sounds of speech and music. These responses are even stronger than the brain response to other natural sounds [10]. Music, like language, consists of a series of sequential events that are perceived by hearing and require complex information processing [11]. Based on the results of the research a comparative model of neural networks that describe similar and different features of music and language was developed. Brown with colleagues considers that "the model assumes that music and language show parallel combined generativity for complex sound structures (phonology) but distinctly different informational content (semantics)" [12]. Another model for research of music based on the assumption of participants classified as musicians and non-musicians was used in different studies in which compares brain functions in both groups. These studies show the role of music in the development of human cognitive abilities [13]. Activation of neuronal patterns in response to music can show whether a participant has music education [14]. The acquisition of music changes the perception of hearing and the related organization of the brain, so it characterizes the plasticity of the brain. Processes related to the perception of music are also connected with motor and auditory perception and speech. Musicians are better and faster at the recognition of artificial language compared to non-musicians [15]. The results of the research suggest that music training can transform the synchronization of the neural networks involved in the processes of verbal memory [16].

Extensive information on the influence of music on the peculiarities of brain function and the role of different areas of the cerebral cortex in the understanding of music has been provided using the electroencephalography method. An electroencephalogram (EEG) is a recording of the dynamic of the oscillations of electric potentials of neurons in the brain. Spectral analysis of EEG signals helps to get important information about the effects of music on the human brain [17]. EEG and Event-Related Potential (ERP) methods are also used to study the relationship between computer language and neural processes. It was found that the embedded system (programmable system which have a fixed functionality) leads to the changes in the electroencephalograms of computer linguists [18]. Music stimuli induce motor system activities, and it has a powerful emotional trigger effect [19]. The analysis of working memory task between professional pianists and control group people, showed significant differences in EEG under different electrodes. These differences are due to the peculiarities of perception of words and sounds. Significant differences were observed also for the iconic memory tasks in the right hemisphere of these two groups [20]. EEG recording of frontal and parietal brain lobes while listening to music showed the importance of these lobes in music perception [21]. It was found that EEG high frequency beta and gamma waves carry information about musical mode [22].

## 2 Methods

### 2.1 Participants

The study was performed with 23 volunteers (ages of 19–24) from the University of Latvia (LU), Faculty of Education, Psychology and Art. Two experimental groups were recruited, "musicians" from students of musical pedagogy program and "non-musicians" from students of other study programs without any active musical relationship. Musician group contained 12 participants, from them there were 8 females and 4 males (mean age of respondents was 21.83 ± 2.48 years). The non-musician group contained 13 female participants (mean age 23.92 ± 5.54). The experiment was performed in a special quiet room and during recording EEG participants assumed a comfortable position in a chair, during experiment light was turned off.

## 2.2 Procedure

Music stimuli in the present study were compiled from different genres – 3 representing Latvian chorus songs and 3 representing orchestral music. The first minute of each music's sounds was recorded on one audio file mixed with silence in such manner – silence 1 minute, then stimulus 1 minute (see Figure 1), for data analysis 15 seconds EEG recorded intervals before and during stimulus was used. For auditory stimulus presentation Observer XT version 10.5 (Noldus Information Technology) and RealPlayer (RealNetworks, Inc) software's were used for purpose of the audio signal synchronization via unipolar input channel on the EEG headbox. Participants heard the sound in the ears loudspeakers (Samsung). After the experiment was completed, the research goal was explained to participant, if he (she) has questions. All procedures had been accepted by the local LU ethical review board.

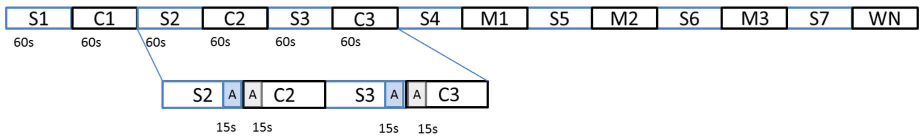



**Fig. 1.** Diagram of the experiment and data analysis

*Notes:* S1 – S7 – silence, the 60s; C1 – C3 – chorus songs, 60s; M1 – M3 – instrumental music, 60s; WN – white noise, 60s. A – data of the recorded EEG for further analysis, 15s.

## 2.3 EEG recordings and data preprocessing

EEG was recorded with a sample rate of 512 Hz. Cut-off frequencies were 0.1–100 Hz. 19 standard electrodes of the 10–20 system were used. Electrodes were fixed to the scalp with electrolyte gel at electrode positions, and generally impedances were < 5 kOhm. A ground electrode was placed at the forehead. Schwarzer EEG-29T recording system with Coherence version 6.1.3.417 application software (Natus Europe GmbH) was used.

Recorded EEG data were analyzed offline using Matlab 2020a (The MathWorks, Inc) using EEGLAB (http://sccn.ucsd.edu/eeglab) with some custom scripts. The scalp EEG was re-referenced to the computed average reference. 50 Hz noise in EEG signals was rejected using bandpass filters with value 48–52 Hz. Then EEG signals with performance errors or remaining artefacts exceeding ± 100 µV in any channel were rejected using ICA procedure (based on online EEGLAB tutorial https://eeglab.org/tutorials/06_RejectArtifacts/RunICA.html) from data before processing. All cleaned EEG trials were inspected visually before further computation. EEG waves spectral properties were calculated with standard EEGLAB function SPECTOPO and then power was calculated for each wave's bands using the handwritten script in Matlab. Data statistical analysis (ANOVA) were performed using Statistica (TIBCO Software Inc., data analysis software system, version 13, http://tibco.com).

## 3 Results and discussion

The analyses of the basic rhythms of EEG – delta, theta, alpha, beta and gamma frequency ranges and power in the processes connected with the perception and cognition of music for experimental groups was carried out. In this study, the changes in the wavelength ranges of the maximum frequency and the wave frequency range power, which is calculated as the integral range was analysed. Multiple factors statistical analysis was performed in the three-way repeated-measures analysis of variance (ANOVA). Factors selected for analysis were – the first factor groups" with two levels – musician's vs non-musicians, the second factor EEG waves with five levels – delta, theta, alpha, beta and gamma, the third factor – stimulus with four levels – silence before the chorus, silence before music, chorus and instrumental music.

### 3.1 EEG spectral analysis ANOVA

For analyses, the following classically connected with perception and cognition of music and language regions of interest (ROI) were selected – Broca's area with two electrodes F7 and F3 (left hemisphere) and opposite (right) hemisphere electrodes F8 and F4, Wernicke's area with T5 and P3 as well as two opposite side T6 and P4 electrodes and auditory cortex areas with T3 and T4 electrodes.

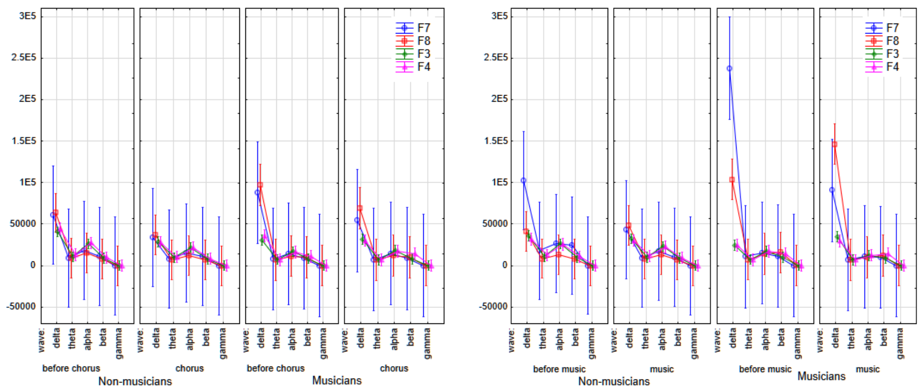
In both lexical regions (Broca's and Wernicke's area) and auditory cortex first – Groups factor has statistically significant influence $F = 5.76$, $p < 0.001$ (see Table 1) with higher Broca's area dominance comparing both zones. The second finding from ANOVA was that in all ROI two factors contribution – Groups and EEG waves are statistically significant, with prevalence into sound processing area $F = 6.39$, $p < 0.01$ (see Table 1). This indicates that musicians and non-musicians processed audio stimulus in a different way. More detail data analysis (mean and standard deviation) is described below where each ROI is analysed (see Figures 2–4).

**Table 1.** ANOVA Tests of significance for experimental factors (groups, EEG waves, stimulus) for Broca, Wernicke and auditory cortex ROI

| Factors | Values | F | Effects Df | p |
|---|---|---|---|---|
| Intercept | 0.51 | 139.87 | 10 | 0.001 |
| Groups | 0.96 | 5.76 | 10 | 0.01 |
| EEG waves | 0.45 | 32.53 | 40 | 0.01 |
| Stimulus | 0.98 | 0.90 | 30 | 0.62 |
| Groups*EEG waves | 0.84 | 6.39 | 40 | 0.01 |
| Groups*Stimulus | 0.98 | 0.74 | 30 | 0.85 |
| EEG waves*Stimulus | 0.94 | 0.76 | 120 | 0.98 |
| Groups*EEG waves*Stimulus | 0.95 | 0.59 | 120 | 0.99 |

### 3.2 EEG wave band on the different ROI analysis

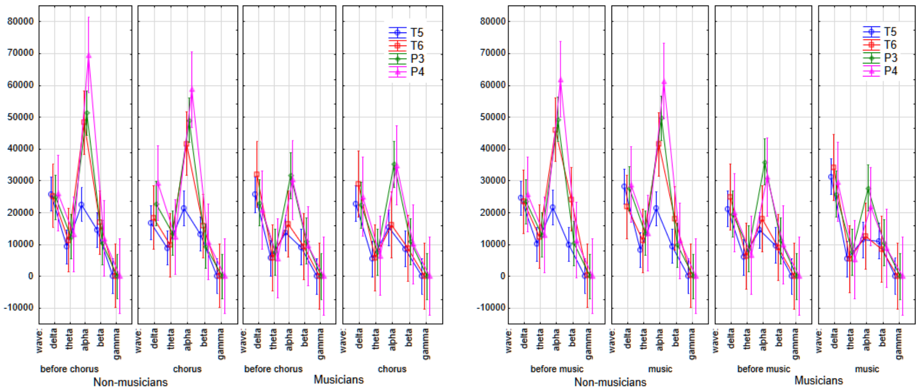
The main difference between two groups was on delta EEG band on the Broca's area in cases of instrumental music stimulus presentation with two electrodes F7 237712.2 ± 31366.2 $\mu V^2$ (mean ± standard error) before music and 90530.13 ± 31366.2 $\mu V^2$ during music listening in musicians group comparing with 02613.6 ± 30135.67 $\mu V^2$ before music and 43217.6 ± 30135.67 $\mu V^2$ during music listening in non-musicians' group, same tendency observed in opposite hemisphere under F8 electrode 103946.01 ± 12634.14 $\mu V^2$ before and 146516.01 ± 12634.14 $\mu V^2$ during music listening in the group of musicians and in the group of non-musicians 41171.3 ± 12138.49 $\mu V^2$ before and 48821.6 ± 12138.49 $\mu V^2$ during listening music. But in the case of the choral stimulus, no differences between two experimental groups were observed (see Figure 2).




(a) (b)

**Fig. 2.** Non-musicians vs musicians example of EEG waves spectral density under different stimulus condition on the Broca area electrodes (a- chorus song, b- instrumental music)

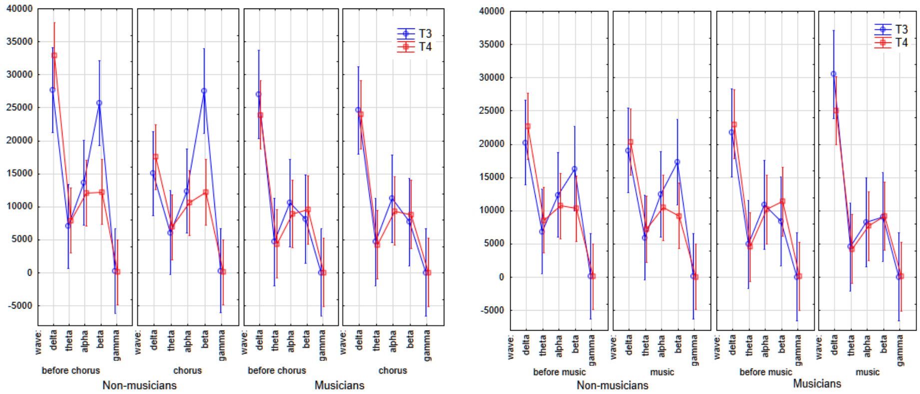
In Wernicke's area, the main differences between the two groups were on alpha EEG band in all stimulus presentation cases in the non-musicians group. Also mean values in P3 are higher than mean values in T5 in all groups, and this difference in non-musicians' group are clearly presented (see Figure 3). For P3 in silence before chorus 51377.35 ± 3545.36 $\mu V^2$ for non-musicians, 31718.58 ± 3690.13 $\mu V^2$ for musician's and during the listening chorus for non-musicians 48955.57 ± 3545.36 $\mu V^2$, 35253.75 ± 3690.13 $\mu V^2$ for musician's, same in silence before instrumental 49294.1 ± 3545.36 $\mu V^2$ for non-musicians, 35949.9 ± 3690.13 $\mu V^2$ for musician's and during listening instrumental music 49633.33 ± 3545.36 $\mu V^2$ for non-musicians, 27773.77 ± 3690.13 $\mu V^2$ for musician's groups. Also, under electrodes, P4 and T6 non-musicians group showed higher values than musicians.




**(a)** **(b)**

**Fig. 3.** Non-musician's vs musicians example of EEG waves spectral density under different stimulus condition on the wernicke area electrodes (a- chorus song, b- instrumental music)

In Auditory areas, main differences between the two groups were on beta EEG band in all stimulus cases and observed values are higher in the non-musicians' group under T3 electrode (see Figure 4). For silence before chorus 25715.83 ± 3252.51 $\mu V^2$ in non-musicians and 8136.88 ± 3385.32 $\mu V^2$ in musicians and during listening chorus 27561.97 ± 3252.51 $\mu V^2$ and 7679.93 ± 3385.32 $\mu V^2$ in both groups. The similar tendency under instrumental music, 16319.91 ± 3252.51 $\mu V^2$ and 8392.84 ± 3385.32 $\mu V^2$ before the stimulus and 17311.94 ± 3252.51 $\mu V^2$ and 9046.22 ± 3385.32 $\mu V^2$ in non-musicians and musicians' groups. Interesting that under sound stimulus (choral or instrumental) musicians group showed higher values in delta waves band under both electrodes – T3 24627.57 ± 3385.32 $\mu V^2$ in the choral 30517.85 ± 3385.32 $\mu V^2$ in instrumental music listening in comparison with non-musicians 15056.09 ± 3252.51 $\mu V^2$ in the choral and 19044.78 ± 3252.51 $\mu V^2$ during listening instrumental music and T4 23943.54 ± 2629.95 $\mu V^2$ chorus music 25047.25 ± 2629.95 $\mu V^2$ instrumental for musicians' group against non-musician peoples 17513.51 ± 2526.77 $\mu V^2$ choruses and 20325.78 ± 2526.77 $\mu V^2$ instrumental music. Comparing power values of the electrodes for musician T4 beta band is higher but for non-musician T3 values are higher and this difference is presented.




**(a)** **(b)**

**Fig. 4.** Non-musician vs musicians example of EEG waves spectral density under different stimulus condition on the auditory area electrodes (a- chorus song, b- instrumental music)

### 3.3 Discussion

Recent scientific studies have shown that Broca's area (which functions are related to the speech) is structurally and functionally heterogeneous area of the brain. Some parts of Broca's area share neurocognitive functions, while others are connected to other areas of the brain and are involved in other functions. From the opinion of Fedorenko and Blank there is a fundamental difference between the two sub-regions of Broca's area, which probably play different roles in cognition: the first is related to language and the second to various other functions and their coordination. It is possible that these two regions of Broca's area carry out linguistic and cognitive processing in different ways [23]. Musicians have been found to have a higher sensitivity index in a certain Broca's area.

In our study main differences between groups in delta waves, diapason was observed, that possible indicate higher remembering" activity during listening to music in musicians' group in comparison with non-musicians.

Elmer group source-based EEG study with ROI over inferior parietal lobe and Broca's area suggest that musicians have better sensitivity index (d') during auditory presented pseudowords. This change goes parallel with increased theta waves coherence in the left hemisphere. Non-musicians had higher functional connectivity in the right hemisphere. There were no differences between both groups during a passive listening control or in the rest condition. These results show task-specific differences between musical perception and word learning [24]. The literature suggests that musicians differ from non-musicians in several specific skills, which may range from right-hemisphere expansion in novices to left-hemisphere dominance in music professionals. Well known that musicians have stronger bilateral neural connectivity and brain plasticity caused by extended musical training, and there is a difference between recognition of the music and other auditory stimuli like the voice in comparison with non-musicians. Sound discrimination ability, as well as musical memory, seems to be distributed with a prevalence in the left hemisphere, but both hemispheres are involved [25].

In our study, it was observed that in Broca's area – musicians have a higher asymmetry between left- (F7) and right- (F8) hemispheres in case of listening to instrumental music in delta waves diapason. In Wernicke's area opposite picture was observed – non-musicians have higher hemisphere asymmetry in both electrodes of the left hemisphere – T5 and P3, and for the right hemisphere in the T6 and P4 electrodes in alpha waves diapason. The same findings were observed in auditory ROI – non-musicians have higher asymmetry in beta waves diapason in comparison with musician group during listening to different types of music.

The results of the research of Koelsch group indicate that different chord-sequences (consisted of five chords, which were specifically mixed) were differently recognized and separated in Wernicke area according to the chord's specifics [26]. This indicates that processing of music is very similar to the processing of speech and similar cortical networks that consist of front-lateral, anterior, and posterior temporal lobe structures are involved in the processing of this information. This result supports the point of view that musical elements of speech play a significant role in the processing of language, and both hemispheres are involved in this process.

Research has suggested that structural and functional brain plasticity results from long-term musical training, that produce differences in cognitive functions between musical educated and non-educated persons [27]. The research has shown that musicians in comparison with non-musicians, have a faster response speed, a higher response intensity, and a higher response power of beta waves [28]. The change in alpha rhythm found in our study correlate with studies in binaural beat stimulation that can modulate the strength of brain wave oscillations. The binaural beat is the presentation to every ear of two sinusoidal tones with small frequency mismatch what yields an auditory illusion of a beating. Brain frontal, temporal and parietal lobes are involved in the processing of binaural auditory beats. Alpha band network was modulated by low-frequency binaural beats and alpha oscillations seem to be involved in the perception of binaural beat illusion [29].

The musician's brain could be used as a model in the brain plasticity studies not only in music perception but also in speech and related studies.

## 4 Conclusion

The peculiarities of the brain bioelectrical activity during listening to a music show that musicians and non-musicians' processes audio stimulus in a different way. The main difference between musicians and non-musicians in the Broca's area is in beta EEG band. EEG values are higher in the non-musicians group. During sound stimulus (chorus or instrumental music) musicians group shows higher EEG values in delta waves band under T3 and T4 electrodes in the choral instrumental listening in comparison with non-musicians' group. EEG wave spectral analysis is an effective and reliable method for analyses the dynamics of neural processes in the brain during music listening tasks.

## 5 Acknowledgment

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