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The impact of music on the bioelectrical oscillations of the brain

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In this article we conclude the main scientific studies into the changes in the bioelectrical brainwave activity that occur while listening to music. A brainwave spectral analysis, derived from findings of electroencephalograms, is a powerful tool to obtain deep and objective insights into the effects of music on the brain. This capacity is being investigated in various contexts. Starting with a healthy population, studies also seek to determine the impact of music in such conditions as disorders of consciousness, psychiatric diseases, and chronic conditions, as well as to further explore the role of music for rehabilitation purposes. Supplemental investigations in this field are needed not only to deepen the knowledge of general neurophysiology of listening to music, but also to possibly open new perspectives for its broader use in clinical practices.

Keywords: electroencephalogram, music, spectral power

INTRODUCTION

An electroencephalogram (EEG) is a recording of the oscillations of electric potentials in the brain, sometimes referred to as a "window of the mind". Is widely used to evaluate the synaptic actions in the cerebral cortex, which are moderately to strongly connected to the state of the brain. They reflect and identify baseline brain electrical activity as well as the changes that happen during distinct deep sleep stages, anaesthesia, epileptic seizures, and cognitive events. Also, although brain activity is spontaneous and does not depend on specific sensory stimuli, it might be easily altered by them, and these changes can also be seen in the findings of EEGs (1).

Voltage traces recorded by EEG electrodes are described as waves. They are defined in terms of three parameters: amplitude, frequency, and phase. Another important unit describing brainwaves in an EEG is brainwave spectral power expressed in Volts-squared per Hz (V^2/Hz). This unit derives from the spectral analysis of the electroencephalogram. Absolute brainwave power describes the power of certain frequency components present in the time period whereas relative brainwave power reflects the role of a specific frequency in the context of all frequencies, e.g., the percentage of the absolute power of a certain frequency in the whole power spectrum.

Depending on the frequency, waves can be categorised as delta (1–4 Hz), theta (4–8 Hz), alpha

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(8–13 Hz) (which is sometimes divided into alpha 1 (8–10 Hz) and alpha 2 (11–13 Hz)) and beta (more than 13 Hz). Another category of very high (30–40 Hz) frequencies is referred to as gamma waves (1).

Every type of a brainwave can roughly indicate distinct states of the brain although this connection varies strongly depending on various factors.

For example, very low frequencies (delta activity) are dominant during deep sleep, coma, and anaesthesia.

The theta rhythm is usually observed in drowsiness and the states of low-level alertness. A very specific type of theta referred to as “frontal midline theta” can be observed during various tasks such as mental calculation, working memory, error processing, and meditation (2).

The alpha rhythm is typically seen in at least three different types, which are different in topography and function. First, the posterior alpha rhythm, originating from the parietooccipital cortex, is dependent on the alertness and attentional factors. Second, there is the mu rhythm, which is dominant in central electrodes and is related to the somatosensory cortex and movement. Third, the tau rhythm originates from the auditory cortex. It is important to stress that alpha power and brain activity are inversely related. This means that, roughly speaking, the bigger the alpha power, the less active the brain (1). The alpha rhythm is typically predominant in the awake-resting state, either relaxed and comfortable (desynchronised tonic slow alpha) (3) or concentrated (4) (phasic desynchronised alpha), as well as in the case of alpha coma (1).

The beta rhythm is usually associated with cortical integrity, increased alertness, and cognitive processes (2). Beta waves primarily occur during the awake-state, and an increase in beta power can be caused by stress, strong emotions, and tension. The absence of beta waves is seen in the cases of cortical injuries and might be used as an indicator of compromised cortical functions (5).

As mentioned before, brainwaves can be altered by various external stimuli. Auditory stimuli and especially music are among the most interesting. As the famous British neurologist Oliver Sacks states, “our auditory systems, our nervous systems are tuned for music. Perhaps we are a musical species no less than a linguistic one” (6). Indeed, starting with Alfred A. Tomatis’ ideas and, later, Don Campbell’s book *The Mozart Effect*, scientists have never stopped investigating the impact of music on the brain. Although there are many different ways and angles from which to observe this effect, in this article we will try to conclude the main findings of the spectral analysis of brainwave activity that occurs while listening to music.

GENERAL NEUROPHYSIOLOGY OF LISTENING TO MUSIC

Scientific studies investigating the effect of music on the brains of healthy people often use Sonata in D Major for Two Pianos K448 by Wolfgang Amadeus Mozart. In fact, this piece has inspired Campbell’s *The Mozart Effect*. According to current literature, this sonata causes a significant increase in relative alpha band power, as well as in a median frequency of background alpha rhythm in young adults and healthy elderly people. Interestingly, during this study no significant changes were observed while listening to Beethoven’s “Für Elise” (7).

Sonata K448 is also known to improve spatial performance. A few brainwave patterns correlating to this improvement are lowered theta power in the left temporal area; increased beta range in the left temporal, the left frontal, and the right temporal regions; increased alpha 1 power left temporally. Again, these patterns have been found to emerge while listening to this particular piece (8).

The effect of music, however, might not be dependent on a specific piece. According to scientists, music that is personally liked by the subjects turns out to enhance EEG power spectra globally and also across bandwidths. The effect is best seen in beta and alpha frequencies in the right frontal and temporal regions. Disliked music, musical improvisations, or white noise (a random signal having equal intensity at different frequencies) do not seem to have the same impact, although white noise also produces similar responses on the left hemisphere (9).

A study investigating traditional Indonesian music found that it significantly increases beta power activity, averaged over the posterior two thirds of the scalp. In this case, however, no effect on alpha waves was seen. Also, comparing the periods of silence and music, listening to music recruited new areas of the brain into the active processes, such as the posterior part of the precuneus, which also had an increase in cerebral blood flow. According to the authors, this effect may reflect the impact of music on cognitive processes, such as music-evoked memory recall or visual imagery (10).

Not only listening (perceiving) but also imagining music elicits the posterior alpha activity. Actually, imagery causes significantly greater alpha power in posterior areas than does perception. This effect might indicate the inhibition of non-task relevant cortical areas, in this case, posterior areas, which are not so important for the perception of music and therefore inhibited stronger while listening to music rather than while imagining it (16).

The valence of music may also be a factor determining the effect it has on the brain. An impact of positively and negatively valenced sounds (e.g., consonant and dissonant chords) was described in a study, which investigated seven patients with intracranial electrodes implanted for presurgical evaluation. Results revealed an increase in the power of low frequency brainwaves in the auditory cortex and, later, a more gradual increase in theta and alpha power in the amygdalae and orbitofrontal cortex, which seem to be important for a higher analysis of music. Also, three subjects saw greater power in alpha, theta and low beta waves in the orbitofrontal cortex while listening to consonant rather than dissonant sounds. No changes in brainwave patterns in the amygdalae were seen when comparing dissonant and consonant sounds (11). This effect is also seen in another study, which shows that positively valenced pieces of music tend to elicit a greater theta power in mid-frontal electrodes than do negatively valenced pieces. Furthermore, this effect increases towards the end of a piece of music. According to the authors, this theta activity is connected not only to attentional but also to emotional functions (2).

The pleasantness of music is a subjective measurement reported and evaluated by the person being investigated. This measurement helps to evaluate how different people perceive auditory stimuli, and it is known to correlate with the frontal alpha waves asymmetry (12). For example, children with monolateral cochlear implants show less frontal alpha patterns associated with pleasant music than does the control group (13). This might be due to the fact that people with cochlear implants hear sounds differently than the healthy population. More specifically, these subjects might be unable to discriminate between "normal" and dissonant music and therefore lack an ability to appreciate the pleasantness of "normal" music (14). The knowledge of the musical sphere can also influence the impact of music on the bioelectrical activity of the brain. It is known that professional musicians exhibit more intense patterns of emotional arousal while listening to music than amateurs. Professionals also have higher central activation of beta 2 band, whereas amateurs exhibit higher right frontal alpha activation (17).

MUSIC IN THE CASES OF PATHOLOGY

Disorders of consciousness

The impact of music on the bioelectrical activity of the brain in people with various illnesses is also being investigated and disorders of consciousness is one the most popular spheres of studies of this field.

Investigations of the impact of music on comatose patients with traumatic brain injuries have shown that applying long-term music therapy decreases their quantitative EEG value $\delta + \theta/\alpha + \beta$ (1) 8 by decreasing the amount of low frequency waves (δ and θ) and increasing the amount of high frequency waves ($\alpha + \beta$). Since coma usually presents a decreased and slowed brainwave activity, this shift to an increased amount of high frequency waves shows an activation of the brain.

The success of music therapy is also being investigated in patients with an unresponsive wakefulness syndrome – a condition wherein the patient awakes from coma (can open the eyes) but remains unresponsive (does not respond to commands, shows only reflex movements) (19). Studies show that their favourite music can reduce the theta/beta ratio and theta power in these patients. The decrease of the theta/beta ratio basically results from decreased theta amplitudes, which show a shift of the dominant rhythm into the alpha band – that might reflect the tendency of recovering brain integrity (20).

The minimally conscious state is typically seen in EEGs as a spectral peak in the theta range. Studies show (21, 22) that music personally liked by a patient may induce alpha frequency amplitude peaks in both the right and the left hemispheres (9).

These effects reveal that music can have an activating effect on the brain in people with disorders of consciousness.

Psychiatry

Long-term music therapy is also being investigated in psychiatric patients. It has been known that music significantly increases alpha and reduces beta activity over time in patients with major depression, schizophrenia, or anxiety symptoms. Music therapy also causes anxiety levels to drop. Authors give two explanations for these changes: pleasant music either helps patients enter a state of tranquillity or distracts them from unpleasant feelings by stimulating the auditory receptors. This may be done by mitigating the sympathetic nervous system and reducing its activity (23). In another study, which investigated music therapy in patients diagnosed with depression, long-term music therapy revealed a significant increase in the left frontotemporal alpha power, as well as in the left frontocentral and the right temporoparietal theta power. Together with these changes, the reduction in Depression Scale – Anxiety Subscale scores was observed, indicating reduced anxiety after music therapy. According to authors, these patterns reveal action and treatment effects of music therapy on cortical activity in depression, as well as a possible neural reorganization (24).

Music therapy is also beneficial for patients with schizophrenia. In a study analysing the impact of long-term music therapy on schizophrenia patients, increased alpha activity in prefrontal, frontal, temporal, and parietal lobes was also observed. Nonetheless, these patients also showed an increased cognitive function and positive behaviour compared to the control group, which did not participate in music therapy sessions (25).

Chronic conditions

There are many chronic conditions which might benefit from music therapy, for example, chronic pain. Pain is generally a very wide concept, which can be influenced by many psychological and physiological factors. Music, along with many other types of therapy, may be a possible therapeutic approach to chronic pain. It is already known that listening to preferred music decreases delta wave power in the cingulate gyrus. This usually happens in the cases of distracted attention, so music seems to distract the individual's attention from unpleasant feelings (27). This effect may be used to relieve the patient's negative emotions in chronic pain therapy.

The impact of music on patients with oncologic diseases is also being analysed. Studies show that music therapy (in particular – monochord sounds) can have a relaxing effect on patients undergoing chemotherapy. This impact is seen as an increase in posterior theta waves and a decrease in midfrontal beta and posterior alpha bands, as well as a reduction in the degree of anxiety (26).

There are some cases, however, when music does not have a significant effect on a brainwave activity. In subjects with mild cognitive impairment (MCI), no impact of music (neither Mozart's Sonata K448 nor Beethoven's "Für Elise") on the bioelectrical activity of the brain was recorded (7). This phenomenon might be explained by the compensatory brain plasticity which therefore could induce additional brain activation in patients with MCI resulting in a failure to notice the changes in brain frequencies while listening to music.

Rehabilitation

Music therapy is also used as a therapeutic means for rehabilitation purposes and there are some interesting studies being done in this field. For example, it has been found out that a preferred tempo (which usually peaks at slightly over 120 beats per minute and varies in populations) correlates with the beta frequency in motor areas of the brain. This suggests that tempo preferences are determined by the neural activity in the motor cortex and therefore differ in populations (28). In addition, according to recent findings, beta brainwaves show a periodic modulation, which is congruent not only with the beat of auditory stimuli but also with the rhythm in rhythmic finger tapping tasks in post-stroke patients, with both paretic and non-paretic hands. According to authors, there might be a common mechanism across auditory and motor processing that could open a wider path for music therapy in stroke rehabilitation (29).

CONCLUSIONS

To sum up, the impact of music on the bioelectrical activity of the brain is being investigated in various contexts. Starting from a healthy population, studies also seek to determine the effect of music in such conditions as disorders of consciousness, psychiatric diseases and chronic conditions, as well as to further explore the role of music for rehabilitation purposes. A brainwave spectral analysis is a powerful tool for these studies as it provides deep and objective insights into the effects of music on the brain. Further investigations in this field would not only deepen our knowledge of musical processing but would also open new perspectives for the use of music in clinical and therapeutic practices.

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MUZIKOS ĮTAKA SMEGENŲ BIOELEKTRINIAM AKTYVUMUI

Santrauka

Straipsnyje glaustai apžvelgiami pagrindiniai smegenų bangų pokyčiai, pasireiškiantys tiriamajam klausantis muzikos. Smegenų bangų, fiksuojamų elektroencefalogramose, spektrinė analizė yra galingas įrankis išsamiai ir objektyviai analizuojant muzikos įtaką smegenims. Šis tyrimo metodas naudojamas daugelyje įvairių kontekstų. Straipsnyje nagrinėjamos studijos, naudojančios spektrinės analizės metodą, aprėpia tiek sveikus individus, tiek pacientus su įvairiomis patologijomis, pavyzdžiui, sąmonės sutrikimais, psichiatrinėmis ar lėtinėmis ligomis. Taip pat aptariamas muzikos vaidmuo reabilitacijoje. Papildomi tyrimai šioje srityje yra svarbūs, nes jie ne tik pagilintų suvokimą apie muzikos klausymo metu vykstančius neurofiziologinius procesus, tačiau taip pat galėtų atverti naujas perspektyvas jos panaudojimui klinikinėje praktikoje.

Raktažodžiai: elektroencefalograma, muzika, spektrinė galia