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THE POWER OF MUSIC

Nada Pop-Jordanova
Macedonian Academy of Sciences and Arts

ABSTRACT: It is well documented that music is a basic and ubiquitous socio-cultural sphere in humans. Across human cultures music was a source of affective and pleasurable experience, moving people both physically and emotionally. It is confirmed that music shapes brain structure and brain function. Research in the neuroscience of music suggests that neural oscillations synchronize with musical stimuli. Fundamental dynamical principles based on known neural mechanisms can explain basic aspects of music perception and performance, as summarized in ‘neural resonance theory’. Music is an integral part of every human society. Music can bring pleasure, calm anxiety, soothe sorrow, inspire and/or stimulate movement, and promote social connections. Musical experiences may also have the remarkable ability to enhance brain and cognitive development, improve function and well-being, optimize the quality of life, and possibly ameliorate the symptoms of a broad range of diseases and disorders.

Key words: music, brain, development, neuroscience, EEG.

Извадок
Добро е документирано дека музиката е основно и сеприсутно социо-културно поле кај луѓето. Музиката низ човечките култури била извор на афективно и пријатно искуство, раздвижувајќи ги луѓето и физички и емоционално. Потврдено е дека музиката ја обликува структурата и функцијата на мозокот. Истражувањата во невронауката за музика сугерираат дека невронските осцилации се синхронизираат со музичките стимули.

Фундаменталните динамички принципи засновани на познати невронски механизми можат да ги објаснат основните аспекти на перцепцијата и изведбата на музика, како што е сумирано во „теоријата на невронска резонанца“.

Музиката е составен дел од секое човечко општество. Музиката може да донесе задоволство, да ја смири вознемиреноста, да ја смири тагата, да инспирира и/или стимулира движење и да промовира социјални врски. Музичките искуства може да имаат и извонредна способност да го подобрат развојот на мозокот и когнитивниот развој, да ја подобрат функцијата и благосостојбата, да го оптимизираат квалитетот на животот и евентуално да ги ублажат симптомите на широк спектар на болести и нарушувања.

Клучни зборови: музика, мозок, развој, невронаука, ЕЕГ.

I. INTRODUCTION

It is well documented that music is a basic and ubiquitous socio-cultural sphere. It is proven that human beings along the evolution were realised only as a social entity and cannot existed without communication with other people. So, the communication our thoughts and feelings with other people is an integral part of human life and existence. Commonly this communication involves two nonverbal informational channels: facial expression and vocal expression (Paulmann and Pell, 2011). Literature confirmed that cultural background has a significant input on how people use facial and vocal signals for conscious evaluation of the emotional meanings of these expressions choosing from multisensory stimuli of the environment. In this context, there are cultural differences in sensitiveness of facial expression or to vocal cues during emotional processing. In this regard, it was confirmed that people for East are more sensitive to vocal cues and people from Western countries are more sensitive to facial expressions. These cultural differences are interpreted as a result of culture-specific social norms that regulate how emotions are communicated in socially appropriate ways. Music across human cultures was a source of affective and pleasurable experience, moving people both physically and emotionally. It is confirmed that music shapes brain structure and brain function. Research in the neuroscience of music suggests that neural oscillations synchronize with musical stimuli. Fundamental dynamical principles based on known neural mechanisms can explain basic aspects of music perception and performance, as summarized in ‘neural resonance theory’. Neural Resonance Theory (NRT) suggests that music perception and enjoyment arise from the natural oscillations of the brain and body that synchronise with musical elements like rhythm and melody. This theory highlights how our brains physically resonate with music, influencing our sense of timing and

Pleasure, and has implications for therapy and education. Additionally, it was proposed that people anticipate musical events not through predictive neural models, but because brain-body dynamics physically embody musical structure. The interaction of certain kinds of sounds with ongoing pattern-forming dynamics results in patterns of perception, action and coordination that we collectively experience as music. Universal structures may have arisen in music because they correspond to stable states of complex, pattern-forming dynamical systems. This analysis of empirical findings from the perspective of neurodynamic principles imposed the new light on the neuroscience of music and what makes music so powerful (Harding EE. Et all, 2025).

Neural mechanisms of music : Humans primarily perceive music through the auditory system. Therefore, when the auditory system is functioning normally, listening to music typically induces brain activity.The neural mechanisms of music listening and appreciation are not yet understood completely. Still, neural activity in the auditory system synchronizes to sound rhythms, and brain-environment synchronization is thought to be fundamental to successful auditory perception. Sound rhythms are often operationalized in terms of the sound's amplitude envelope. (Weineck K. et all, 2022). In this way, music with slower beat rates, high familiarity, and easy-to-perceive beats evoke the strongest neural response. It was demonstrated the importance of Spectro-temporal fluctuations in music for driving neural synchronization, and highlight its sensitivity to musical tempo, familiarity, and beat salience.The apparent relationship between tempo (beats per minute) of music and the desire to move (i.e. feet tapping) while listening music suggest that music tempo may evoke movements related to activity in the brain motor areas (Daly J. Hallowell J et all, 2014). The ability to perceive a regular beat in music and synchronize to this beat is a widespread human skill. Fundamental to musical behaviour, beat and meter refer to the perception of periodicities while listening to musical rhythms and often involve spontaneous entrainment to move on these periodicities.

The involvement of amygdala and orbitofrontal cortex in the processing of valanced stimuli is well established. Research confirmed that amygdala has an initial sensitivity to the physical properties of valanced stimuli. In contrast, the orbitofrontal cortex sensitivity to sensory information did not precede differentiation based on affective judgements (Omigie D. et al, 2014).Study of Pincheiro AP et all (2015) confirmed the positive effects of musical training on the perception of vocally expressed emotions; namely, the effects of musical training on event-related potentials (ERP) correlates of musical prosody processing (neutral, happy and angry intonation). Prosody refers to the rhythmic and intonational aspects of language, including elements like stress, pitch, and tempo that contribute to the meaning and emotional tone of speech. It plays a crucial role in how we understand spoken language and can affect the interpretation of sentences. EEG recording confirmed in musician reduced P50 amplitude and N100 in non-musicians. Musicians especially were more accurate in recognising angry prosody in sentences. Findings suggest that auditory experience by extensive musical training may impact different stages of vocal emotional processing. Professionals exhibited different and more intense patterns of emotional activation when listened music i.e. impact of music experience on emotional reactions.

In general, music is an ecologically valid and complex stimulus that conveys certain emotions to listeners through compositions of musical elements. In the last decade, EEG-based emotion classification during musical listening has gained increasing attention due to its promising potential applications such as musical affective brain-computer interface (ABCI), neuro marketing, music therapy and implicit multimedia tagging and triggering. Listening to music, especially to subjectively preferred songs, engages brain pleasure pathways. A study using positron emission tomography (PET) measured regional cerebral blood flow changes in response to the subject’s chosen highly pleasurable music, which would evoke the experience of “chills” or “musical frisson”. With increasing intensity of music-evoked pleasure, cerebral blood flow changes were registered in brain regions associated with reward, motivation, arousal, and emotions, namely ventral striatum, midbrain, amygdala, orbitofrontal, and ventral medial prefrontal cortices. When we listen to a melody, the activity of our neurons synchronizes to the music: in fact, it is likely that the closer the match, the better we can perceive the piece. However, it remains unclear exactly which musical features our brain cells synchronize to. The ‘amplitude envelope’ (how the intensity of the sounds changes over time) could be involved in this phenomenon, together with factors such as musical training, attention, familiarity with the piece or even enjoyment. Whether differences in neural synchronization could explain why musical tastes vary between people is also still a matter of debate.The analyses revealed that three types of factors were associated with a strong neural synchronization. First, a tempo of 60-120 beats per minute elicited the strongest match with neuronal activity. Interestingly, this beat is commonly found in Western pop music, it is usually preferred by listeners, and often matches spontaneous body rhythms such as walking pace. Second, synchronization was linked to variations in pitch and sound quality (known as ‘spectral flux’) rather than in the amplitude envelope. And finally, familiarity and perceived beat saliency – but not enjoyment or musical expertise – were connected to stronger synchronization. These findings help to better understand how our brains allow us to perceive and connect with music. However, the ability to perceive a regular beat in music and synchronize to this beat is a widespread human skill. Fundamental to musical behaviour, beat and meter refer to the perception of periodicities while listening to musical rhythms and often involve spontaneous entrainment to move on these periodicities. The frequency-tagging approach was used to understand the perception and production of rhythmic inputs. This approach is illustrated by recording the human electroencephalogram responses at beat and meter frequencies elicited in various contexts: mental imagery of meter, spontaneous induction of a beat from rhythmic patterns, multisensory integration and sensorimotor synchronization. The research supports the view that entrainment and resonance phenomena subtend the processing of musical rhythms in the human brain. More generally, they highlight the potential of this approach to help us understand the link between the phenomenology of musical beat and meter and the bias towards periodicities arising under certain circumstances in the nervous system. Entrainment to music provides a highly valuable framework to explore general entrainment mechanisms as embodied in the human brain (Nozaradan S., 2014). Fig. 1 shows frequency spectra in auditory condition, the right hand-tapping condition (red) and the left hand-tapping condition (green), averaged across all scalp channels.

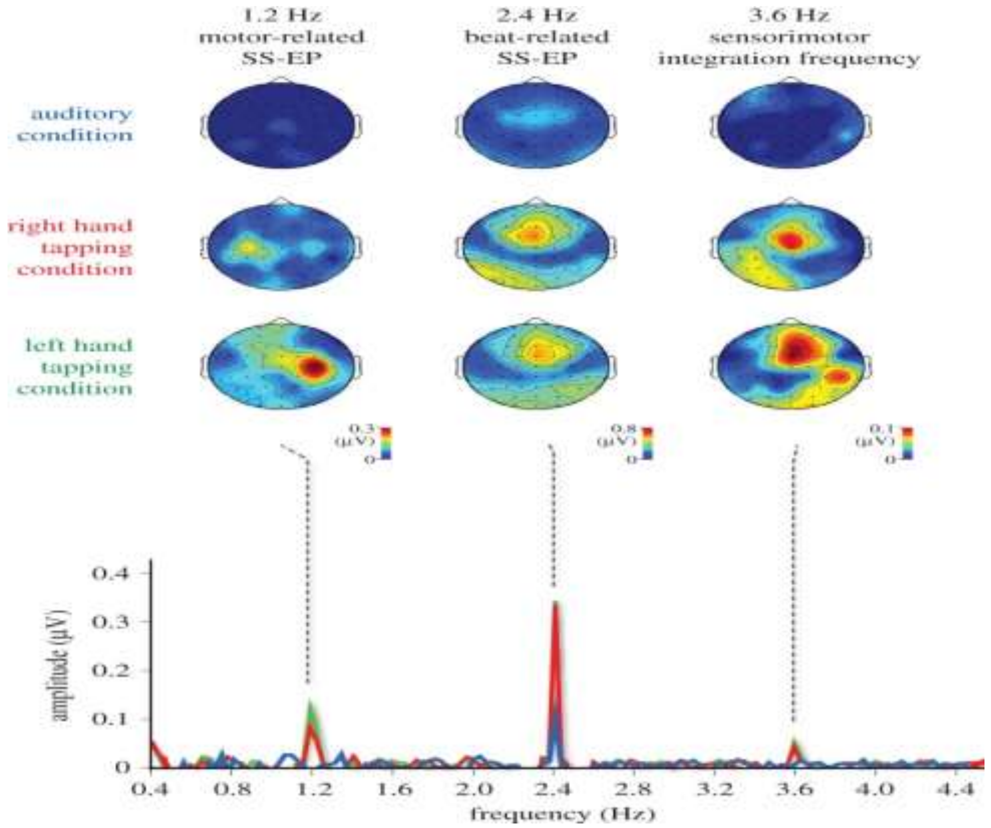

Fig. 1. Group-level average frequency spectra (Hz) of the noise-subtracted EEG amplitude signals obtained in the auditory condition (i.e. listening without moving; in blue), the right hand-tapping condition (red) and the left hand-tapping condition (green), averaged across all scalp channels[9].

In all conditions, the 2.4 Hz auditory beat elicited an SS-EP at 2.4 Hz. As shown in the corresponding topographical maps, this beat-related SS-EP was maximal over fronto-central electrodes. In the left and right hand-tapping conditions, the 1.2 Hz hand-tapping movement was related to the appearance of an additional SS-EP at 1.2 Hz. As shown in the topographical maps, this movement-related SS-EP was maximal over the central electrodes contralateral to the moving hand. In these two conditions, an additional SS-EP emerged at 3.6 Hz, referred to as cross-modulation SS-EP, whose scalp topography showed patterns similar to both beat-related and movement-related SS-EPs topographies. Selective enhancement of the responses elicited at beat and meter frequencies are referred to as beat- and meter-related SS-Eps in the EEG spectrum. State-evoked potentials (SS-EPs) observed in the EEG spectrum at frequencies corresponding to the rhythmic pattern envelop.Neural entrainment to rhythmic patterns has been proposed as a mechanism that underlies beat perception and could explain individual differences in sensorimotor synchronization abilities.

Nevertheless, the neural and cognitive mechanisms behind beat perception remain an active research area. Research on music and brain function has suggested that the temporal pattern structure in music and rhythm can enhance cognitive functions especially the memory. The study of Noboa ML. et all, (2025) examined whether neural entrainment to rhythmic patterns, cognitive resources, specifically working memory and musical background predict sensorimotor synchronization skills in adults. Using electroencephalogram (EEG), it was recorded steady-state evoked potentials (SS-EPs) while participants passively listened to short tone sequences featuring syncopated (tones missing from certain beats) and unsyncopated (tones present on every beat) rhythms. Results showed increased steady-state evoked potentials (SS-EPs) at beat-related frequencies (1.25 Hz and its harmonics, 2.10/2.50 Hz, 5 Hz), indicating faithful neural tracking of the rhythms. Contrary, stronger neural entrainment to unsyncopated rhythms was associated with greater tapping variability and lower synchronization accuracy. In contrast, working memory capacity positively predicted tapping consistency, suggesting that automatic beat-based predictions as reflected in neural entrainment may reduce the flexibility needed for rhythm production. Musical background was not a significant predictor of tapping performance, while evaluation of working memory suggests that just working memory capacity support rhythm production skills by maintaining internal representations of time intervals. These results challenged the assumption that stronger neural entrainment universally enhances synchronization skills and highlighted the multidimensionality of rhythm processing, and the complex relationship between neural entrainment, cognitive resources, and sensorimotor synchronization skills.

Music processing in the brain - the perception of melody, harmony and rhythm, has been studied as an auditory phenomenon using passive listening paradigms. However, when listening to music, we actively generate predictions about what is likely to happen next. This enactive aspect has led to a more comprehensive understanding of music processing involving brain structures implicated in action, emotion and learning. Music perception, action, emotion and learning all rest on the human brain's fundamental capacity for prediction - as formulated by the predictive coding of music model. This formulation of music perception and expertise in individuals can be extended to account for the dynamics and underlying brain mechanisms of collective music making. This has important implications for human creativity as evinced by music improvisation. These recent advances shed new light on what makes music meaningful from a neuroscientific perspective (Vuust P. et al, 2022). The research in the neuroscience of music suggests that neural oscillations synchronize with musical stimuli. Based on principles such as resonance, stability, attunement and strong anticipation, it was proposed that people anticipate musical events not through predictive neural models, but because brain-body dynamics physically embody musical structure (Harding EE. Et all, 2025). Attunement refers to the process of bringing oneself into harmony or understanding with another person, often involving emotional responsiveness and connection. It is important for forming relationships and can be seen in how individuals recognize and respond to each other's needs and feelings. The interaction of certain kinds of sounds with ongoing pattern-forming dynamics results in patterns of perception, action and coordination that we collectively experience as music.Briefly, music is an integral part of every human society. Music can bring pleasure, calm anxiety, soothe sorrow, inspire and/or stimulate movement, and promote social connections. Musical experiences may also have the remarkable ability to enhance brain and cognitive development, improve function and well-being, optimize the quality of life, and possibly ameliorate the symptoms of a broad range of diseases and disorders.

While music is a ubiquitous component of every human society, music-based interventions may encompass listening to music, performing music, music-based movement, undergoing music education and training, or receiving treatment from music therapists. Music and music-based interventions (MBI) engage a wide range of brain circuits and hold promising therapeutic potentials for a variety of health conditions. The power of music to influence movement, emotion, learning, and behaviour is enormous. Very important finding is that the brain processes music and language through some similar mechanisms. For example, the rhythm of music and the grammatical structure of language both stimulate the Broca’s area in the left hemisphere, a region closely associated with language processing. Research has shown that musical education can enhance children’s language skills, including vocabulary, grammar comprehension, and verbal expression. Thus, there exists a close connection between music and language, and brainwave signals serve as a method for studying brain activity, which can be applied to examine the relationship between musical and linguistic expression at the neural level. In music therapy, especially the receptive music therapy, therapists need to engage in dialog with patients and monitor their emotional changes. Electroencephalography (EEG), with its high temporal resolution, captures the brain activity during music and language processing.

‘Mozart Effect’ : Music has been used to reduce anxiety and relax the minds in patients suffering from a number of medical diseases. The ‘Mozart Effect’ was initially described by Rauscher et al. (1993). They reported that students scored nine points higher on spatial tasks after listening to Mozart’s Sonata for two pianos in D major, K.448 (Mozart K.448) for 10 min when compared to the same time of silence or relaxation. Since then, benefits from listening to Mozart K.448 are reported beneficial for tinnitus, cognitive rehabilitation and epilepsy. Mozart's music, by activating task-relevant brain areas, enhances the learning of spatio-temporal rotation tasks (Jausovec N. et al, 2006). Fig. 2 summarize music-based interventions used in practice.

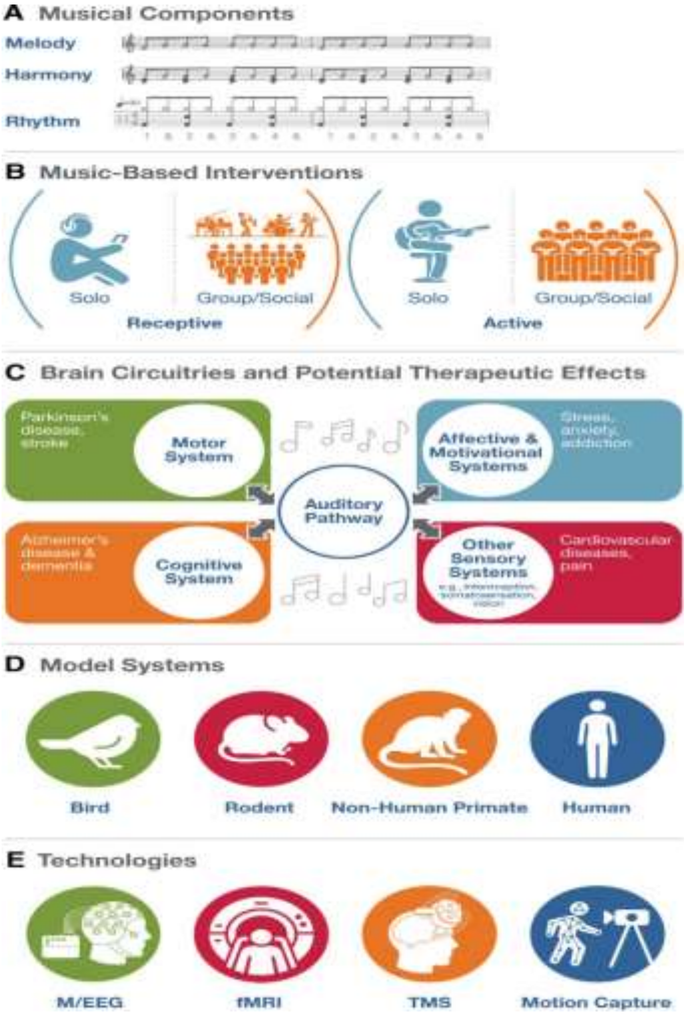

Fig. 2. Evidence-based research on music-based interventions[11]

A, Illustrative examples of components of music, including melody, harmony, and rhythm.

B, Examples of the modes of delivery of MBIs. Receptive modes: when a subject passively listens to musical components. Active modes: when a subject actively performs musical components. Solo modes: when a subject is passively listening to (receptively) or actively performing musical components. Group/Social modes: when a subject is receiving or performing music in a group setting, or when a subject is, or subjects are, interacting with a music therapist or therapists.

C, Brain circuits engaged in potential therapeutic effects by MBIs. Musical components are first processed through the auditory pathway. Evidence has emerged to support neural network connections between auditory and motor or affective/motivational systems, which may underlie MBI's therapeutic effects on related diseases, such as PD, stroke, stress, anxiety, and addition. The neural network connections between the auditory pathway and cognitive or other sensory systems, such as interoception, somatosensation, nociception, and vision, remain to be explored for implications on diseases, such as Alzheimer's disease, dementia, cardiovascular diseases, and pain.

D, Examples of biological/model systems studied in MBI research include birds, rodents, nonhuman primates, and humans.

E, Examples of technologies used to study MBIs. Examples of brain imaging technologies include MEG, EEG, and fMRI. An example of brain stimulation technology is TMS. An example of behaviour capturing technology is a motion-capture and tracking system.

Mozart music has been shown to decrease interictal EEG discharges and recurrence of clinical seizures in both adults and children. The evaluation comprised sleep quality and behavioural disorders, auto/hetero aggression, irritability and hyperactivity in drug resistant epileptic children. (Coppola G. et al. (2015). Mozart music increases alpha band and medium frequency index of background alpha rhythm activity (linked to memory cognition and open mind to problem solving) (Magee WC, O'Kelly J. 2015). However, there is incomplete understanding of the time course of the development of music perception, particularly regarding implicit knowledge of music-syntactic regularity. (Jentschke S. et al. (2014). Research sowed neurophysiological responses to music-syntactically irregular harmonies. The N5 a brain response usually present in older children and adults was not observed indicating that processes of harmonic integration are still in development in this age. But, 30-month-olds children already have acquired implicit knowledge of complex harmonic music-syntactic regularities and possesses musical information according to this knowledge.

In the study of Noboa ML. et all (2025) on quantitative traits of developmental psychopathology, genetic factors are diminished in favour to the environmental influences. Authors have argued that practically all children exhibit symptoms of inattention, aggression, anxiety and sadness, and emotional dysregulation, and that these symptoms are influenced by genes and environments (both negative and positive). They hypothesized that purely categorical diagnostic conceptualizations belie the true nature of behaviour, as well as its underlying biology. Following from this dimensional conceptualization of psychopathology, children with attention-deficit/hyperactivity disorder (ADHD) are not categorically different from children who do not meet criteria for ADHD; rather, they are quantitatively more severe in that they possess more symptoms than children who do not meet ADHD criteria. Interestingly, they have found that normal, subclinical variance in psychopathological traits (e.g., inattention, anxious/depressed symptoms) largely map to the same neural networks posited to underpin clinically significant psychopathology (e.g., ADHD, major depressive disorder). In this context, subclinical anxious/depressed symptoms among healthy youths are related to cortical thickness maturation within aspects of the medial prefrontal network—a network heavily implicated in the mediation of clinically significant mood and anxiety symptomatology. Similarly, subclinical inattention and hyperactivity among healthy youths are associated with cortical thickness maturation in fronto-parietal areas—regions implicated in the pathophysiology of ADHD, as well as attentional control and behavioural inhibition.

Related to autistic spectrum, the study of Trent G. et all (2014) reached several conclusions about autism's genetic architecture: its narrow-sense heritability is ~52.4%, with most due to common variation, and rare de novo mutations contribute substantially to individual liability, yet their contribution to variance in liability, 2.6%, is modest compared to that for heritable variation. Taken together, these findings in typically developing children added support to the idea that human emotions and behaviours exist on a continuum, rather than in categories, and further, that each type of behaviour can be mapped to distinct networks in the human brain. In sum, the findings that genes and environment influence the degree to which a child expresses a trait combined with the findings that variation in cortical thickness and developmental effects correlate to the degree that a child expresses a behaviour almost immediately leads to the desire to investigate environmental factors that might influence traits via influencing brain structure and function. To put it simply, there are environmental factors that might serve to influence aspects of brain maturation. It was intriguing motive to determine how health-promoting activities might be associated with better outcomes in children and reported on the behavioural genetic architecture into the health benefits of exercise, music, and reading. One such wellness activity is learning to play a musical instrument. Structural MRI studies confirmed that the training effect is more influential than a genetic predisposition. Brain changes were observed in motor areas, the corpus callosum, and the right primary auditory region, all areas important for music performance and auditory processing. In addition, unexpected areas increased in volume compared to those of the controls; these included various frontal areas, the left posterior peri-cingulate, and the left middle occipital region. Additionally, there is evidence that short-term musical training in early childhood correlates with musically relevant motor and auditory cortical changes. In their review, Bilhartz et al. note a significant association between early musical instruction and spatial-temporal reasoning abilities. The results of their study support the hypothesis that there is a significant link between early music instruction and cognitive growth in specific non-musical abilities. Even minimally musically treated children in this study scored significantly higher than the control children on one measurement of abstract reasoning ability.

Fig. 3 shows brain area where cortical thickness is associated with the age x years of playing music.

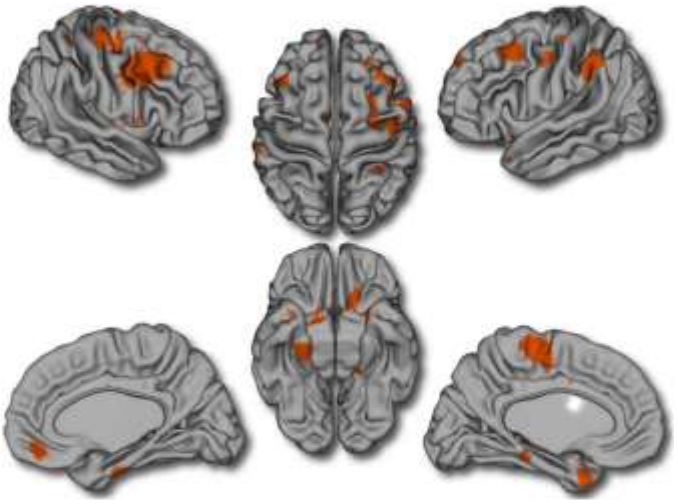

Fig. 3. Brain areas where local cortical thickness is associated with the "Age × Years of Playing" interaction[10]

These findings showed that music training was associated with cortical thickness development in the premotor and primary motor cortices and it is not surprising given that both regions contribute to the control and execution of movement. It is posited that the premotor region plays a particularly important role in the preparation and sensory guidance of movement, both of which are key characteristics of music training. In the same way, the supplementary motor area is thought to play a role in the planning and coordination of movement, again key skills in music production. Many other studies confirmed the power of music listening and performance in children on the developmental pathway. In this context, worldwide the music is used as a nonpharmacological trigger for better grow and development of young children and adolescents (Fasano MC. Et al, 2023; Lin LC. Et al. 2014). Finally, it must be accentuated that music has a profound impact on human emotions, capable of eliciting a wide range of emotional responses, a phenomenon that has been effectively harnessed in the field of music therapy. Given especially the close relationship between music and language, researchers have begun to explore how music influences brain activity and cognitive processes by integrating artificial intelligence with advancements in neuroscience (Lin X. et al 2025). The differences in EEG signals between different emotions during speech are more pronounced compared to those in a quiet state. In the classification of EEG signals for speaking and quiet states, using deep neural network algorithms can achieve accuracies of 95.84% and 96.55%, respectively.

II. CONCLUSION

Music possesses has a remarkable capacity to induce transformative changes in the brain, fostering neuroplasticity and reshaping neural networks. Music's positive effects on cognition encompass memory, attention, and learning, highlighting its potential as a cognitive enhancer. Music profoundly impacts emotional states, offering therapeutic benefits in alleviating stress, anxiety, and depression. Music's role in promoting physical health is evident especially in pain management and its potential for improving physical rehabilitation outcomes. Music's unique ability to foster social bonding and communication underscores its significance in promoting social well-being. The recognition of music's therapeutic potential has given rise to music therapy as a non-pharmacological intervention for a wide range of diseases.

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Note: This article is motivated by my own experience about the influence of music on my brain activity. Namely, my repeated QEEG recording showed absence of the alpha band in the brain map, which means no possibility to relaxation either meditation. In my brain only beta waves were dominated. After that, as provocation, simultaneous listening of classical music during QEEG recording resulted with the emerge of alpha brain waves in a few minutes. Just this experience stimulated me to write the book entitled Music and Emotions, MANU, 2017 (in Macedonian)[1]. In this book I summarized known published information related to music influence on the emotional brain.

In this article I will accentuate only the important newest knowledge related to the power of music on the brain functioning and development.