ISSN 2835-4138 (digital) IJES Year (2024), Issue/Vol (6/1)
https://doi.org/10.47806/ijesacademic Pages (91-119)

Cognitive neuroscience and music education: Relationships and interactions

Güncel Gürsel Artıktay[1]

Abstract

This article examines the relationship between cognitive neuroscience and music education, evaluating the impact of cognitive neuroscience on musical learning, performance, and teaching strategies. The first section establishes the purpose and scope of the article, followed by an emphasis on the foundations of cognitive neuroscience in the second section. Cognitive neuroscience is explored in terms of music perception, mental processes, and fundamental concepts related to learning and memory. The third section, focusing on cognitive processes in music education, delves into the cognitive foundations of musical knowledge, addressing topics such as melody and rhythm perception and cognitive development in instrumental education. The fourth section discusses the neuroscientific analysis of musical performance, stage fright, brain activity, creativity, and mental processes. The fifth section discusses cognitive neuroscience-based teaching models, the neuroscientific foundations of student-centred approaches, and the role of technology in music education. The sixth section highlights future perspectives and research directions, recommendations for future studies, contributions of new cognitive neuroscience findings to music education, current developments in the intersection of music and cognitive neuroscience, and suggestions for future research. In the concluding section, the summarised article's significant findings and contributions are emphasised, drawing attention to potential areas for future examination and application. This article aims to serve as a comprehensive resource for readers interested in understanding the connections between cognitive neuroscience and music education, providing a foundation for further research in this field.

Keywords: cognitive neuroscience, music education, cognitive processes, musical performance, teaching strategies

Bilişsel Sinirbilim ve Müzik Eğitimi: İlişkiler ve Etkileşimler

Özet (Türkçe)

Bu makale, bilişsel sinirbilim ve müzik eğitimi arasındaki ilişkiyi inceleyerek, bilişsel sinirbilimin müzikal öğrenme, performans ve öğretim stratejileri üzerindeki etkilerini değerlendiriyor. İlk bölümde, makalenin amacı ve kapsamı belirlenmiş, ardından ikinci bölümde ise bilişsel sinirbilim temelleri üzerinde durulmuştur. Bilişsel sinirbilim, müzik algısı ve bilişsel süreçler, öğrenme ve hafıza ile ilgili temel kavramlar ele alınmıştır. Müzik eğitiminde bilişsel süreçlere odaklanan üçüncü bölümde, müzikal öğrenmenin bilişsel temelleri incelenmiş, melodi ve ritim algısı ile enstrüman eğitiminde bilişsel gelişim konularına yer verilmiştir. Dördüncü bölümde, müzikal performansın sinirbilimsel analizi, sahne korkusu ve beyin aktivitesi, yaratıcılık ve bilişsel süreçler ele alınmıştır. Beşinci bölümde, bilişsel sinirbilime dayalı öğretim modelleri, öğrenci merkezli yaklaşımların sinirbilimsel temelleri ve teknolojinin müzik eğitimindeki rolü tartışılmıştır. Altıncı bölümde, gelecek perspektifler ve araştırma yönlendirmeleri üzerinde durulmuş, yeni bilişsel sinirbilim bulgularının müzik eğitimine katkısı, müzik ve bilişsel sinirbilim alanındaki güncel gelişmeler ve gelecekteki araştırmalar için öneriler sunulmuştur. Son bölümde ise özetlenen makalenin önemli bulguları ve katkıları vurgulanmış, gelecekteki inceleme ve uygulama alanlarına dikkat çekilmiştir. Bu makalede, bilişsel sinirbilim ve müzik eğitimi arasındaki bağlantıları anlamak ve bu alanda daha fazla araştırma yapmak isteyen okuyucular için kapsamlı bir kaynak sunmak hedeflenmiştir.

Anahtar Kelimeler: bilişsel sinirbilim, müzik eğitimi, bilişsel süreçler, müzikal performans, öğretim stratejileri

[1] Res. Assist., İstanbul Teknik University, Türkiye, artiktay@itu.edu.tr

APA citation style: Artıktay, G., G. (2024). Cognitive neuroscience and music education: Relationships and interactions. *International Journal of Educational Spectrum, 6*(1), 91-119. https://doi.org/10.47806/ijesacademic.1402953

Submission Date: December 11, 2023
Acceptance Date: December 31, 2023
Published Date: February 29, 2024

Introduction

Cognitive neuroscience is a discipline that investigates mental processes, brain activity, and learning mechanisms, with potential applications in music education. Music education is a process that aims to develop students' musical skills and a significant discipline that strengthens individuals' emotional expressions, cultural connections, and the ability to establish meaningful communication among them. However, understanding and optimising the cognitive mechanisms underlying musical learning processes can enhance the music education experience for educators and students. In this context, comprehending the critical connections between cognitive neuroscience and music education is crucial to understanding learning processes.

The overarching goal of this article is to illuminate the interaction between cognitive neuroscience and music education, identify critical connections between these disciplines, and discuss methods to make music learning processes more effective.

The first section of the article will focus on the fundamental concepts of cognitive neuroscience, providing a basic framework to understand how mental processes operate. Subsequently, in the second section, the effects of cognitive neuroscience on music learning processes will be examined, presenting various perspectives to understand interactions between musical learning and perception, memory, and learning mechanisms.

The third section will assess the impact of cognitive neuroscience on musical performance processes, focusing on topics such as stage fright. The fourth section will address teaching strategies based on cognitive neuroscience and the role of technology in music education. This section aims to provide insights into how teaching strategies can be integrated with mental processes and how technology can contribute to innovative applications in music education.

The article's final section will discuss future perspectives and proposed research directions in music education and cognitive neuroscience. In this segment, beyond current knowledge, considerations will be given to how future efforts can shape discoveries and contribute to a better understanding of the connections between music education and cognitive neuroscience.

The Relationship Between Cognitive Neuroscience and Music Education

As Peterson (2011) emphasised, interdisciplinary research across biology, neuroscience, and cognitive science investigates the interaction between the brain and music. This multidisciplinary approach highlights the integration of cognitive neuroscience into music education studies and underscores the mutual influence between these two domains.

The relationship between music education and cognitive neuroscience is a complex and multifaceted subject. Gkintoni et al. (2023) noted that neuro-musical education seeks to understand how these two disciplines interact by combining cognitive neuroscience and music.

As indicated by Ramón et al. (2021), playing, listening to, and creating music involve nearly all cognitive functions, making it essential to comprehend the effects of music on the brain. This underscores the significant role of cognitive neuroscience in understanding mental processes in music and how music education can contribute to their development.

Music education can enhance plasticity by influencing brain regions such as the auditory cortex and frontal cortex (Collins, 2013), thereby altering the shape and function of the brain. Research suggests that music education shapes brain development, leading to changes such as neuronal plasticity and neurogenesis (Hyde et al., 2009). Furthermore, as highlighted by Zimmerman and Lahav (2012), experiences of making and listening to music establish a robust connection between music and brain function by influencing various systems in the brain.

Music education impacts the brain and positively influences language skills, attention, planning, and other cognitive abilities (Villamizar, 2021). Studies focusing on enhancing cognitive functions related to musical elements, such as rhythm and timing, have generated significant interest in this field (Thaut et al., 2014).

While the positive effects of music education on language and cognitive skills are acknowledged, there is a need for further research on how musicians shape brain structures and the assessment of education from a developmental perspective (Zuk & Gaab, 2018).

Recently, there has been a growing emphasis on the increasing importance of creativity in music education programs. Beyond teaching notes, music education can support cognitive processes such as creativity and improvisation (Landau & Limb, 2017). Research using the electrophysiological method called "brain-stimulated potential analysis" has examined the effects of music education on multiple cognitive functions, brain structure, and functional connectivity (Yu, 2018). Additionally, neural processing models can help us understand functions associated with music processing in the brain (Collins, 2013). These models play a crucial role in explaining neural activity in the brain.

In summary, the relationship between music and cognitive neuroscience emphasises the impact of music on the brain and mental abilities. This relationship is an example of an interdisciplinary approach as it seeks to understand the interaction between music education and cognitive neuroscience. It may be complex, but a body of evidence indicates a significant impact of music education on brain development, cognitive functions, and plasticity. The collaboration between cognitive neuroscience and music education is a critical step in understanding the cognitive and neural mechanisms underlying learning and performing music.

The cognitive science of music is increasingly being utilised in music education departments to enhance student's learning experiences and cognitive development. The application of cognitive science to music education is evident in various aspects, such as the impact of music on cognitive development (Hallam, 2010), the use of mental models in interactive music education platforms (Yang, 2018), and the examination of music pedagogy from the perspective of 4E cognitive science (Schiavio & Schyff, 2018).

Interactive music education platforms are digital tools that provide students with an interactive learning experience. According to Yang's (2018) study, these platforms aim to support students' music learning by employing cognitive models. Additionally, 4E cognitive science, as emphasised in the study by Schiavio and Schyff (2018), is an approach that examines cognitive processes based on the concepts of "embodied, embedded, extended, and enactive," suggesting that cognition develops not only within the brain but also through interaction with the environment, body, and experience. This perspective supports an approach in music education that actively encourages students to use their senses, bodies, and environments.

Instructional design involves planning and organising learning processes to create a practical learning experience in music education. The cognitive, social, and teaching presence concepts from a community framework are helpful in the instructional design and facilitation of online music courses (Johnson, 2017).

Embodiment, as highlighted in the study by Leman and Maes (2015), aims to understand cognitive processes in music perception. In this context, there is an increased interest in exploring the role of the body in understanding mental processes in music perception (Leman & Maes, 2015).

Furthermore, the cognitive aspects of music in primary school curricula are being examined, including servant, emotional, social integration, and equal cognitive styles (Berke & Colwell, 2004). Practical teaching strategies are being developed to maximise the benefits of music and general cognitive development (Bugos, 2015).

Moreover, the application of cognitive psychology in music note cognition for exceptional children is emphasised, highlighting the potential for psychological rehabilitation and improvement in cognitive development and physical coordination (Gong, 2020). Additionally, research is being conducted on the potential of music to encourage oral expression in English as a second language learner, demonstrating the cognitive dimensions of language and music integration (McCormack & Klopper, 2016).

In summary, the infusion of cognitive science into music education is dynamic and diverse. Interactive platforms, guided by mental models, enhance students' musical proficiency. The 4E cognitive science perspective emphasises cognition's interactive and embodied nature in music learning. Exploring cognitive aspects in primary school curricula, employing practical teaching strategies, and applying cognitive psychology highlight the broad impact of cognitive science on music education. This integrated approach enriches learning experiences and significantly contributes to cognitive development within the educational landscape.

Foundations of Cognitive Neuroscience

What is Cognitive Neuroscience?

Cognitive neuroscience is an interdisciplinary field aiming to understand the neural mechanisms of human cognition, including processes such as attention, perception, memory, reasoning, problem-solving, and decision-making (Piwowarski et al., 2019; Palmeri et al., 2017). Various neural pathways and networks associated with different cognitive processes are identified using neurophysiology, electrophysiology, and structural and functional brain imaging (Palmeri et al., 2017).

Furthermore, cognitive neuroscience is closely related to other disciplines, such as philosophy, psychology, and evolutionary psychology, exhibiting an interdisciplinary nature (Ren, 2019; Forster, 2014; "Foundations in Evolutionary Cognitive Neuroscience," 2009). The integration of cognitive neuroscience with social psychology has led to the emergence of social cognitive neuroscience, aiming to understand the neural basis of social cognition and behaviour (Doré et al., 2015; Lieberman, 2005). This integration has provided new insights and methodologies to bridge the gap between social and cognitive neuroscience (Doré et al., 2015).

The emergence of organisational cognitive neuroscience reflects an expansion of cognitive neuroscience to examine interactions in decision-making, behaviours, and organisational contexts (Lee & Chamberlain, 2007; Butler & Senior, 2007). Advances in neuroimaging techniques have played a significant role in the development of cognitive neuroscience. These techniques have enabled research on the working brain, positioning neuroscience as a central discipline in cognitive science (Markič, 2013; Zahn, 2009). Moreover, this field has practical applications in understanding mental health disorders and their neural foundations (Beste, 2022).

Cognitive neuroscience has also contributed to understanding art perception, revealing that individuals respond to the physical features of artworks and what they represent (Smedt & Cruz, 2010). Cognitive neuroscience is an interdisciplinary field encompassing various areas to understand human cognition's neural mechanisms. It has practical applications in diverse fields such as mental health, organisational behaviour, and social cognition. Collaborations with other disciplines and advancements in neuroimaging techniques have expanded its scope and increased its potential for further discoveries.

Music Perception and Cognitive Processes

The perception of music encompasses a vast research domain within the complexity of cognitive processes, particularly extensively examined in disciplines such as music psychology, cognitive neuroscience, and psychology. The influence of music on cognitive, sensory-motor, and emotional processes points to a complex interaction network involving various brain structures (Koelsch, 2009). The neurobiology of music, explicitly emerging as part of cognitive neuroscience investigating the cognition and emotional foundations of music perception, has been highlighted

(Brattico & Pearce, 2013). Furthermore, music contributes to broader theories of higher cognitive processes in humans (Levitin & Tirovolas, 2009).

For instance, the perception of musical rhythm is a complex phenomenon requiring the amalgamation of automatic and controlled processes, indicating the involvement of instinctual and learned cognitive mechanisms (Grahn, 2012). Additionally, findings suggest associations between music perception, production abilities, speech processing, and higher-level language skills (Boorom et al., 2022). This underscores both the intertwining of music perception with language and auditory processing and the impact of music on higher-order cognitive processes.

Moreover, the body mediates music perception, indicating the interconnectedness of music cognition with embodied cognition (Yi et al., 2014). This perspective underscores the critical role of the body in shaping cognitive processes in music perception.

Cognitive processes in music perception generally encompass neural, sensory-motor, emotional, and bodily mechanisms. These processes are intertwined with language processing and embodied cognition, emphasising the multidimensional nature of music perception within the framework of cognitive neuroscience.

Basic Concepts Related to Learning and Memory

Learning and memory encompass a wide range of cognitive processes. Learning is a process that involves acquiring knowledge or skills through experience, study, or instruction. On the other hand, memory represents the ability to encode, store, and retrieve information. These processes are governed by various mechanisms at the fundamental molecular, cellular, and system levels of human cognition (Levenson et al., 2004; Ramamurthy et al., 1998; Gerstner & Yin, 2010; Klann & Sweatt, 2008; Csicsvari & Dupret, 2014; Sewell et al., 2020; Li et al., 2021).

Memory formation involves converging a series of complex events in the brain. Among these events are the regulation of chromatin structure, synaptic plasticity, protein synthesis, and epigenetic mechanisms (Levenson et al., 2004; Klann & Sweatt, 2008; Csicsvari & Dupret, 2014; Li et al., 2021).

The regulation of chromatin structure is a critical molecular mechanism contributing to forming long-term memory. Memory formation involves regulating chromatin structure, which encompasses the organisation of our genetic material, DNA. Specific genes may need to be activated or silenced to form long-term memory. This regulatory process plays a critical role in the permanence of memory by managing genetic changes. Additionally, altered protein synthesis is considered a trigger for forming long-term memory, requiring the production of new proteins. Neurons need specific proteins to store and recall learned information, and protein synthesis facilitates a crucial step in memory formation.

Changes at the synapses, representing connections between neurons, play a crucial role in memory formation. This process, known as synaptic plasticity, occurs by strengthening or weakening connections between neurons. Enhancing or altering communication between neurons can result from synaptic plasticity in forming long-term memory. Epigenetic mechanisms refer to changes in our genetic material. During memory formation, they play a significant role in regulating gene expression. Specifically, they may effectively transform short-term memory traces into lasting long-term memories. The interplay of complex mechanisms, such as the regulation of chromatin structure, synaptic plasticity, protein synthesis, and epigenetic mechanisms, helps us understand memory formation.

Learning encompasses various cognitive processes such as concept formation, perception, attention, problem-solving, decision-making, and thinking (Ramamurthy et al., 1998). The role of memory, particularly in concept learning experiences, has been extensively researched (Bourne et al., 1964; Cahill & Hovland, 1960; Dominowski, 1965). Working memory, the ability to temporarily store and manipulate information, is crucial in cognitive tasks and multimedia learning. The role of memory in relational learning processes has also been examined, supporting a context-based approach to learning and memory.

The interaction between explicit instruction and practice depends on the straight and implicit memory systems in the complex learning task. Vivid memory, representing consciously recalled and directly accessible memory, generally includes consciously remembered information, such as daily life events, learned facts, and personal experiences. This information usually occurs at our conscious level and can be under our control. On the other hand, implicit memory represents a type of memory that is not consciously remembered but affects behaviours. Examples of implicit memory stored in the subconscious include motor skills, habits, and emotional responses. This type of memory develops through repetitions and experiences, emerging without a conscious effort. Both types of memory complement each other, forming a complex memory system.

In conclusion, the fundamental concepts of learning and memory encompass a broad range of cognitive processes, including memory formation, synaptic plasticity, protein synthesis, epigenetic mechanisms, concept learning, working memory, and the interaction between explicit and implicit memory systems. Understanding these concepts is crucial for unravelling the complexities of human cognition and behaviour.

Cognitive Processes in Music Education

Cognitive Foundations of Musical Learning

The cognitive foundations of musical learning involve various neural mechanisms and processes. Music perception and cognitive processes are influenced by auditory mechanisms, which receive sounds and are processed by existing mental resources. There is a complex interaction between sensory input and cognitive processing (Aslan, 2007). Research shows that music affects brain function and behaviour; continuous exposure to music enhances cognitive function and supports neurobiological processes (Harvey, 2020; Haslbeck et al., 2017; Curtis & Fallin, 2014).

An important research area to better understand cognitive processes underlying the comprehension and production of music is the process known as 'statistical learning in music.' This concept generally aims to comprehend the mathematical and statistical principles of musical structure. It statistically analyses relationships between musical elements, repeated patterns, melodic structures, and harmonic transitions. Statistical learning in music emphasises cognitive processes involved in recognising patterns and transition probabilities within the structure of a musical composition, highlighting the importance of sequential and connected components in musical learning (Daikoku, 2018).

On the other hand, the acquisition of instrumental skills is closely related to physical musical activity. The acquisition of these skills, in line with phenomenological theories focusing on cognitive processes to understand bodily perception and interaction with music experiences, emphasises music education's physical and sensory-motor aspects (Kim, 2020). This underscores that music learning involves technical skills and subjective experiences.

A study by Heng et al. (2021) examining the effects of the familiarity of musical style on the emotions triggered by music draws attention to the complex relationship between subjective musical experiences and cognitive processes. In this context, understanding the impact of music on human emotions and how musical experiences affect cognitive processes provides an essential perspective for music education practice.

In activities like music learning, various contextual factors such as environmental conditions, emotional state, and learning environment play a significant role. The 'Contextual Interference Effect' concept emphasises the importance of cognitive processes such as memory, learning, and forgetting in acquiring music skills (Schweighofer et al., 2011).

The cognitive foundations of musical learning go beyond individual skill acquisition, providing insights into the interaction between brain function and development influenced by music education (Thaut, 2005; Collins, 2013; Curtis & Fallin, 2014). These cognitive foundations encompass a wide range of neural and mental processes, from the interaction between sensory input and cognitive processing to the role of statistical learning, bodily musical activity, and emotions triggered by music.

Perception of Melody and Rhythm: Neuroscientific Approaches

The neurology of music has emerged as a sub-discipline of cognitive neuroscience focusing on music perception, mental processes, and emotion (Brattico & Pearce, 2013). Studies indicate that musical ability is an early-developing mental capacity (Vila, 2018). However, rhythm perception has been associated with pre-linguistic grammar comprehension and production skills in the preschool period, and broader mental effects of rhythm processing have been observed (Boorom et al., 2022).

Studies have been conducted using neuroimaging techniques to understand the neural mechanisms of musical rhythm perception and reproduction, aiming to comprehend the neural basis of musical rhythm perception (Grahn, 2012). Research has shown that in some cases, visual rhythms are based on neural processes similar to auditory beat perception, and visual rhythms may create an internal auditory rhythm representation (Grahn, 2012). In this context, the significant role of the basal ganglia in the internal generation of beats has been emphasised, and it has been suggested that an internal auditory rhythm representation may be activated during visual rhythm perception (Grahn et al., 2011). These findings highlight the complex neural processes underlying musical rhythm perception and reveal similarities between visual and auditory perception.

Neuroscientific studies have also proposed a perspective that considers rhythm perception as an interaction between auditory (rhythm) and the pre-structured structure of the brain for music (scale) (Vuust et al., 2014). Specifically, the coordination between the rhythm of music and body movements demonstrates an interaction between what is heard and the pre-structured brain scale. These studies contribute to a better understanding of the neural foundations and cognitive effects of rhythm perception.

In addition to studies on rhythm, neuroscientific evidence provides essential information regarding melody perception. Various methods are employed in these studies to understand melody perception, a fundamental component of musical perception. For example, tonal expectations (expecting a specific note or chord after a particular note in a tonal melody), melodic intention (consciously selected notes and rhythms related to the emotion, theme, or story the composer or performer is trying to express), and musical gestures (physical responses to music) form the basis of melody perception and can influence it.

Furthermore, studies by Herff and colleagues (2017) examining the effects of sequences involving only pitch or rhythm on memory have highlighted the interaction between melody and rhythm in music perception. Multiple pitch estimations refer to predicting the pitches of different notes in a musical piece in advance. This prediction is associated with various elements such as rhythm (the arrangement of notes over time), harmonic periodicity (the arrangement of harmonic relationships), and instrument timbre (the characteristic sound features of the instrument). Studies show that this prediction process occurs within a cognitive framework and plays a significant role in understanding and processing musical elements (Li et al., 2022).

In conclusion, neuroscientific approaches to melody and rhythm perception have significantly contributed to understanding the neural mechanisms underlying music processing. These studies have advanced our knowledge of how the brain perceives and processes music and emphasised the broader cognitive effects of rhythm and melody perception.

Cognitive Development in Instrument Education

Instrumental education plays a significant role in individuals' process of experiencing and expressing music and is acknowledged as a potent learning tool that can also impact cognitive development. While the profound effects of music on mental and emotional development are well-known, instrumental education further enhances this interaction. Acquiring musical skills contributes to developing technical abilities and improves cognitive skills such as problem-solving, focus, discipline, and emotional intelligence.

The importance of instrumental education in cognitive development has been extensively examined and supported by various research findings. Notably, studies have shown a significant impact of musical practices on cognitive development in children (Gromko & Poorman, 1998). Researchers have found that music practices positively influence spatial-temporal task performance in preschool children, involving their understanding of spatial relationships between objects and sequencing skills over time. These findings illustrate that music is a stimulating factor that remains confined to music for children and provides transferable skills.

Another effect of music practices is manifested in the terms 'near-transfer effect' and 'far-transfer effect,' expressing the ability to use a learned skill or knowledge in a context outside the one where it was learned. While the ability to transfer a skill to a similar context or topic is called the 'near-transfer effect,' the capability to use it in a broader or different context is termed the 'far-transfer effect.' For instance, a student who learns to play the piano and can play a specific piece in different tonalities or tempos demonstrates the ability to transfer learned techniques and information to closely related situations within the same musical context. The same student, while playing the piano, also learns the mathematical arrangements of the notes and, in turn, comprehends the relationship between mathematics and music, enhancing the ability to play rhythms accurately. Thus, the transferability of learned mathematical arrangements beyond music reflects the far-transfer effect. Miendlarzewska and Trost (2014) confirmed that music exercises uniquely provide both near and far transfer effects, supporting cognitive development.

Okely et al. (2021) emphasised that instrumental learning is a cognitively stimulating activity and may enhance resistance to age-related brain pathologies. This suggests the potential long-term cognitive benefits of instrumental education. Moreover, evidence indicates positive effects of instrumental education on cognitive development and health at a young age (Balbag et al., 2014; Hille et al., 2011).

Okely et al. (2022) identified a small but statistically significant positive relationship between instrumental playing experience and general cognitive ability. General mental ability encompasses an individual's success in various cognitive processes such as problem-solving, decision-making, memory, attention, and learning. These findings indicate that the experience of playing a musical instrument may positively contribute to the development of these cognitive abilities. The research results suggest that individuals with more experience with musical instruments are likelier to gain more excellent general cognitive ability gains.

In conclusion, the research literature provides robust evidence supporting the importance of instrumental music education in cognitive development. These effects are observed across various age groups, from preschool children to older adults.

Cognitive Neuroscience and Teaching Strategies

Teaching Models Based on Cognitive Neuroscience

Teaching models are increasingly gaining attention with a cognitive neuroscience foundation because of the considerable potential of this method to enhance learning outcomes. As emphasised by Ng and Ong (2018), cognitive neuroscience methods are more commonly employed in educational research today to understand the neural foundations of learning.

For instance, based on current neuroscience research, "brain-based learning" is a prominent instructional approach encompassing our brain's natural learning processes (Soicher et al., 2020). Studies conducted by Maryati et al. (2020) demonstrate that the Brain-Based Learning model enhances students' critical thinking skills and self-regulatory learning attitudes, involving planning, monitoring, and evaluating their learning processes.

Another instructional strategy is the "multimodal learning cognitive theory," which integrates cognitive psychology, cognitive neuroscience, and learning theories. The Multimodal Learning Cognitive Theory emphasises that knowledge is not limited to a single environment or method, highlighting that combining different sensory interventions makes learning more effective. This theory suggests that students are more successful in various learning environments with diverse sensory channels and intelligence types. Diversifying learning materials aims to combine visual, auditory, tactile, and interactive elements that appeal to different intelligence areas, enabling students to understand better and remember concepts. This theory has been applied to medical education, explaining learning with words and images and showcasing practical applications of cognitive neuroscience in educational settings (Mayer, 2010).

Another educational approach, 'Whole Brain Teaching (WBT),' aims for students to establish connections through sensory, emotional, and mental pathways while learning. For example, when teaching subjects in the classroom, this approach involves the teacher's body language, gestures, and interactive participation of students. As stated by Handayani and Corebima (2017), both Brain-Based Learning (BBL) and Whole Brain Teaching (WBT) models are defined as the most effective learning models based on the learning process. Handayani and Corebima (2017) argue that incorporating classical music and gestures enhances cognitive engagement in learning.

On the other hand, cognitive neuroscience stands out as a crucial field for music education. That (2005) emphasises brain function and music perception in music therapy, highlighting a transition from a social science model to a neuroscience-guided model. This transition, supported by Curtis and Fallin (2014), focuses on explaining the interaction between music education and brain development based on increasing evidence in cognitive neuroscience (Curtis & Fallin, 2014).

The impact of music education on cognitive functions is evident. Ho et al. (2003) have shown that music education is remarkably effective in memory processing and may lead to neuroanatomical changes in the left temporal lobe (Ho et al., 2003).

Additionally, reviewing studies on the long-term effects of childhood music education on overall cognitive abilities, Costa-Giomi (2014) and Collins (2013) support the mental benefits of music education (Costa-Giomi, 2014; Collins, 2013).

Collins (2013) discusses the effects of neural processing models on music education, emphasising the necessity of a deeper collaboration between music education and neuroscience to understand the brain's functioning related to music processing. This view is also supported by Hodges (2009), who, particularly under the title "Neuroscience in Music Pedagogy," highlights the importance of applying neuroscience to music teaching and learning.

Lastly, in special education, Gong (2020) underscores the significant potential of music notation cognition in enhancing psychological rehabilitation, cognitive development, and physical coordination in exceptional students. Gong (2020) emphasises the mental benefits of music education across various learning environments.

In summary, it is observed that teaching models are increasingly approached with a cognitive neuroscience foundation. Neural-based learning approaches draw attention due to their potential to enhance learning outcomes, and models such as brain-based learning and multimodal learning cognitive theory exemplify these methods. This collaboration across scientific domains provides an opportunity to develop more effective strategies in education.

Neuroscientific Foundations of Student-Centered Approaches

Teaching strategies incorporating student-centred approaches aim to shift the focus of the learning process from the teacher to the students, encouraging them to gain autonomy and become active participants. Examples of this approach include project-based learning, where students develop a project on a specific topic, engaging in research, data collection, and creative problem-solving. Activities such as group discussions, individual project selection, scenarios dealing with real-world problems, and student self-assessment and portfolio creation are practical examples of implementing student-centred learning.

Music educators also adopt student-centred pedagogies to empower students and enhance their impact on learning (Bautista et al., 2018). This shift is particularly crucial in music education, as traditional practices often lean towards a teacher-centred, top-down instructional style, potentially transforming students into passive recipients of information (Zhuo & Leung, 2019).

Using strategies that promote metacognition among students, i.e., the capacity to understand and direct one's thinking processes, can increase cognitive engagement in music-making and develop critical thinking skills that can be transferred to other disciplines (Benton, 2013).

For instance, in instrumental education, assessment methods such as 'student reflection,' which allows students to assess their learning processes, and 'formative assessment,' aiming to enhance understanding levels by providing feedback to students at every stage of the learning process, are used in harmony with the principles of student-centred approaches (Simon, 2014). Additionally, establishing professional learning communities for music teachers is considered a professional development model that can improve student learning outcomes and reduce teacher isolation (Verdi, 2022).

The cognitive foundations of student-centred approaches in music education are based on constructivist practices highlighting student-centred learning processes, aiming to equip students with problem-solving and critical thinking skills (Weidner, 2020). This transformation in music education emphasises the development of students' musical independence by highlighting creativity, listening, performing, improvisation, and composition as integral parts of the cognitive process (Gage et al., 2019). Moreover, using teaching strategies that promote metacognition has increased students' cognitive engagement in the music-making process, developed musical confidence, and assisted in transferring thinking skills to other disciplines (Machfauzia et al., 2020; Benton, 2013). This approach aims to provide students with lifelong learning skills, enhance autonomy, and instil social responsibility in their learning journey (He, 2016).

In conclusion, the cognitive foundations of student-centred approaches in music education prioritise constructivist practices, metacognition, and creativity while highlighting critical thinking. These approaches aim to empower students with the desire for independent and lifelong learning while transforming the role of music teachers into a more student-centred and democratic approach to music education.

The Cognitive Role of Technology in Music Education

The cognitive role of technology in music education reflects a significant transformation in the development of the discipline. Departing from traditional teaching methods, music education integrated with technology encourages students to engage more effectively in cognitive processes.

E-portfolios and multimedia platforms especially offer options for students to organise and share their learning materials, thus supporting student-centred learning. An e-portfolio is a digital system where students share information and documents about their learning processes, achievements, projects, and experiences, usually on a web-based platform. Unlike traditional portfolios, e-portfolios allow students to organise and share their work in digital format, facilitating them in setting, improving, and monitoring their learning goals. Examples of e-portfolio platforms include Google Sites and WordPress.

On the other hand, multimedia platforms are digital platforms that include various media types, often providing multiple communication features. They can encompass video, audio, text, images, and other media elements. In an educational context, these platforms can support students in learning, content creation, and sharing. They offer tools for students to use different learning styles and preferences, supporting personalised learning. Examples of such platforms include YouTube and SoundCloud. Integrating these platforms into music education has enhanced personalised and flexible learning, increasing access to musical knowledge and strengthening collaborative learning (Dunbar-Hall et al., 2015; Cano & Sanchez-Iborra, 2015).

Artificial Intelligence (AI) is a crucial technology and application area influencing cognitive processes in music education. The primary advantage of AI is its ability to assess students' cognitive skills and analyse learning processes, enabling the emergence of personalised learning paths. This allows students to understand their strengths and improve their weaknesses. Applications like SmartMusic and Music Prodigy are AI-supported platforms that record, assess, and track students' performance progress.

AI can also customise music learning materials and content according to individual learning styles, contributing to more effective learning and understanding of music. Applications like AIVA, Musiio, and Knewton stand out as adaptive platforms personalising learning materials based on students' performances in the field of music education.

Furthermore, AI can assist in teaching music theory, guiding instrument practice, and even helping students create their compositions. This technology is significant in providing student feedback, identifying and correcting mistakes, and offering continuous improvement opportunities. For example, the EarMaster application is an interactive tool that teaches music theory.

AI benefits students and provides music teachers with support for professional development. By supplying resources that include the latest teaching strategies, music education technologies, and pedagogical approaches, AI can enhance the cognitive skills of teachers. Platforms like Soundtrap for Education, which supports music production and collaboration for both teachers and students and TeachRock, which offers digital resources and professional development materials for music teachers, exemplify the support AI can provide.

In addition, cloud computing technology has significantly contributed to the transformation of music education. Cloud applications have facilitated the establishment of modernised online vocal music courses, effectively increased the management of multimedia resources, and strengthened the learning experience (Li, 2017).

In Learning Management Systems (LMS), cloud-based applications like Moodle are practical tools for managing online courses and facilitating student interaction. Teachers and artists can use platforms such as YouTube or SoundCloud to share vocal music lessons and resources, especially offering music educators the opportunity to share their performances and receive student feedback. Additionally, cloud-based audio recording and editing tools, such as Audacity (with cloud integration), allow students to work on interactive music projects. Among virtual classroom and interactive learning tools, Zoom is used to create virtual classrooms, deliver interactive lessons, and provide individual feedback to students. At the same time, Google Classroom is a valuable tool for sharing online resources, assigning tasks, and monitoring progress. These diverse tools enrich the educational process and provide students with different learning experiences.

Despite all these advancements, some educators maintain conservative approaches to music teaching and composition, indicating a gap between the potential of digital technologies and their actual application in music education (Gorbunova & Михуткина, 2020; Boehm et al., 2018). Therefore, further exploration and integration are needed to fully realise the potential of technology in enhancing cognitive processes and learning outcomes in music education.

Future Perspectives and The Future of The Research Process

The Contribution of New Cognitive Neuroscience Findings to Music Education: "Neuromusical Education and Research"

Music, as a significant element of human culture, provides an artistic and emotional experience and offers individuals various cognitive and emotional benefits. Beyond being a tool for emotional expression, music allows us to understand how it affects our brains through the lens of neuroscientific research. In this context, neuro music, which examines the neurological effects of music, plays a crucial role in music education. Music education can enhance students' artistic abilities and strengthen their cognitive functions, memory capacity, and emotional intelligence.

Findings from cognitive neuroscience have made essential contributions to understanding how the brain processes and responds to music. This knowledge can assist educators in adapting their approaches based on new findings to engage students better and improve learning outcomes. The emerging interdisciplinary field of 'neurological education and research,' which combines neuroscience and music, contributes to advancements in cognitive function and quality of life (Gkintoni et al., 2023).

Neuromusical education and research aim to understand how the human brain facilitates music and translate fundamental music research into clinical and educational applications (Loui et al., 2015). This field has focused on various aspects, such as how visual and auditory information is integrated into musical experiences, auditory perception, pitch perception, singing, and the emotional impact of music (Hodges et al., 2005; Tseng et al., 2019; Suendarti & Virginia, 2022). Cognitive neuroscience of music, often relying on brain imaging experiments, has been organised by examining aesthetic experience features such as attention, perception, cognition, emotion, and cultural matrix (how an individual's relationship with music is shaped within a cultural context and how this relationship influences aesthetic experience) (Hodges & Wilkins, 2015).

Neuromusic research indicates that music can enhance cognitive functions by utilising different brain regions to strengthen memory (Weinberger, 2014). Additionally, evidence supports the positive impact of music education on cognitive development and performance in language tasks (individual's language skills in using and understanding), attention, and planning (Villamizar, 2021).

Studies reveal that long-term music education positively affects cognitive abilities, particularly inhibition (impulse control), planning, and executive functions.

This effect can positively influence students' academic performance (Jaschke et al., 2018). Furthermore, research on the role of music in the cognitive rehabilitation of individuals with traumatic brain injury is developing based on findings from neuro musicology and music cognition (Hegde, 2014).

Recently, there has been growing interest in translation studies of neuromusic research regarding its impact on society, cross-cultural differences, and educational applications (Rosenboom, 2014). Research in cross-cultural psychology, cognitive neuroscience, and anthropology can offer methods to assist students in music education, considering the significant variation in human cognitive functions across cultures (Boon, 2018).

Findings about brain plasticity suggest that music education can have positive effects, primarily on auditory processing, motor skills, and memory. Studies on the emotional effects of music can help teachers increase students' motivation and deepen learning by creating emotionally impactful music experiences.

Research on motor skills and coordination emphasises the importance of practising to enhance instrumental skills, providing practical recommendations for music education. Additionally, studies demonstrating the positive impact of music education on memory processes and cognitive skills encourage considering music education as a tool to enhance overall learning potential.

The interdisciplinary nature of neuromusic research has led to collaborative efforts between artists and scientists to facilitate efficient and collaborative research through multidisciplinary communication. Neurological education and research contribute to understanding the neural mechanisms underlying music perception and production. They are a field with practical applications in clinical, educational, and societal contexts.

Future Areas of Study and Application of Neuromusical Education and Research

Music education is an ever-evolving discipline, and future research and applications are poised to expand the potential in this field further. Future studies may focus on specific areas for developing neurological education and a deeper understanding of music-related cognitive processes.

For instance, the relationship between music and language could be one such area. Daikoku (2018) underscores the importance of investigating the potential consequences of overlapping neural connections between music and language for educational applications. Exploring the interactions of neural circuits in the brain between music and language could provide deeper insights into their potential contributions to language learning processes.

Melody, tonality, and rhythm are fundamental musical and language elements. Future research could delve more deeply into how music education may intricately affect language learning processes and the ability to comprehend and express tonal and stress rules in language.

Simultaneously, investigating how the strong connection between music and language can be leveraged in therapeutic applications is also possible. For instance, practical strategies for enhancing language skills in individuals with language disorders could be developed through music therapy. This opens avenues for exploring innovative language therapy and music education practices.

Brain plasticity is adapting to learning, experience, and environmental interactions. Music education can contribute to changes in brain structure by influencing this plasticity process. Future research could conduct specific studies to examine plasticity, such as how playing instruments or engaging in theoretical training may alter neural connections in the motor cortex or auditory regions, especially during childhood. Additionally, the long-term effects of music education on memory, attention, and cognitive abilities in adulthood are worthy topics for further exploration and data collection.

On the other hand, technological integration in education can play a significant role in research. Neuromusical education technologies may encompass innovative tools to support music education and optimise the learning experience. Advancements in this field have the potential to offer students a more effective, personalised, and interactive music education.

For instance, virtual reality (VR) and augmented reality (AR) applications could provide students with a more interactive and participatory music education experience. Alternatively, by implementing personalised education software, students can create an individualised learning plan that adapts to their learning pace with feedback. These applications could be enhanced by incorporating music-related games through gamification methods, making the learning experience more enjoyable and effective. These examples briefly illustrate how neurological education technologies can make music education more effective and interactive.

Conclusion

Summary

This article is designed to comprehensively understand the intricate and significant relationship between cognitive neuroscience and music education. Its primary aim is to comprehend how we can apply the foundations of cognitive neuroscience to music learning processes and, in this context, develop more effective instructional strategies to enhance musical skills.

At the beginning of the article, a general context is provided by focusing on fundamental questions such as what cognitive neuroscience is and how we can understand the connections between music perception and mental processes. Subsequently, cognitive processes in music education are examined under main headings, including the cognitive foundations of musical learning and cognitive development in instrument education, focusing on melody and rhythm perception.

In the following sections of the article, the role of cognitive neuroscience in understanding musical performance is explored by concentrating on topics such as the neuroscientific analysis of musical performance, stage fright, brain activity, creativity, and cognitive processes.

Furthermore, the article delves into the relationship between cognitive neuroscience and teaching strategies, addressing topics such as teaching models based on cognitive neuroscience, the neuroscientific foundations of student-centred approaches, and the cognitive role of technology in music education.

The concluding sections examine future perspectives and research directions, exploring potential areas for future research and investigation in neurological education and review.

In conclusion, the article aims to establish a foundation for understanding the dynamic relationship between cognitive neuroscience and music education. It calls for further exploration and study to strengthen the bridge between research, teaching, and performance areas, enhance future generations' musical abilities more effectively, and better comprehend the impact of music on cognitive processes.

Contributions of the Study

This study is designed to identify the connections between cognitive neuroscience and music education. Its primary objective is to understand how cognitive neuroscience can be integrated into music learning processes and, in this context, to contribute practical insights for the more effective development of musical skills. By shedding light on future research and studies in this field, it aims to bring together the disciplines of cognitive neuroscience and music education.

Additionally, the study aims to examine the neuroscientific analysis of musical performance, intending to provide practical recommendations for musicians to enhance their skills and optimise their performances. Regarding teaching strategies, it delves into how teaching models based on cognitive neuroscience and student-centred approaches can be employed in music education. Thus, it aims to guide educators who seek to make teaching methods more effective and student-focused.

Finally, by focusing on the role of technology in music education, the study attempts to understand how digital tools and applications can enrich the learning experience. In this context, the author shares personal observations and research findings to explore how technology integration in music education can contribute to more effective learning.

In conclusion, this article, illuminated by personal experiences and research, is an effort to comprehensively explain the interaction between cognitive neuroscience and music education. This study will encourage further exploration in this field and contribute to building more bridges that bring these two disciplines together.

Limitations of The Study

Some of the topics covered in this article include areas that are yet to be fully explored or require further research. Additionally, more experimental studies and long-term observations are needed to comprehend the relationship between cognitive neuroscience and music education. These limitations stem from the article's confined scope, considering the breadth of the subject. Nevertheless, they can inspire future researchers to make discoveries and conduct in-depth studies in these areas.

Furthermore, much of the information in the article is based on existing literature and may only encompass some of the latest developments in the field. Therefore, readers should refer to relevant sources for the most up-to-date and comprehensive information.

Many of the topics in the article focusing on the relationship between cognitive neuroscience and music education may involve generalisations and may only partially reflect individual differences. Evaluating the complete effects of these generalisations on individual students or musicians can be challenging due to each individual's varied learning styles and cognitive processes.

In conclusion, these limitations highlight the knowledge gaps in this field and allow future researchers to delve deeper and fill in missing information on specific topics.

References

Aslan, A. (2007). Music perception as a topic of cognitive psychology. *Doğuş Üniversitesi Dergisi, 2*(8), 117-127. https://doi.org/10.31671/dogus.2019.228

Balbag, M., Pedersen, N., & Gatz, M. (2014). Playing a musical instrument as a protective factor against dementia and cognitive impairment: a population-based twin study. *International Journal of Alzheimer's Disease, 2014*, 1-6. https://doi.org/10.1155/2014/836748

Bautista, A., Toh, G., Manchenido, Z., & Wong, J. (2018). Student-centred pedagogies in the Singapore music classroom: a case study on collaborative composition. *Australian Journal of Teacher Education, 43*(11), 1-25. https://doi.org/10.14221/ajte.2018v43n11.1

Benton, C. (2013). Promoting metacognition in music classes. *Music Educators Journal, 100*(2), 52–59. https://doi.org/10.1177/0027432113500077

Berke, M., & Colwell, C. (2004). Integration of music in the elementary curriculum: perceptions of preservice elementary education majors. *Update: Applications of Research in Music Education, 23*(1), 22–33. https://doi.org/10.1177/87551233040230010104

Beste, C. (2022). Overcoming the phenomenological perpetuum mobile in clinical cognitive neuroscience for the benefit of replicability in research and the societal view on mental disorders. *Frontiers in Human Neuroscience, 16*. https://doi.org/10.3389/fnhum.2022.1054714

Boehm, C., Hepworth-Sawyer, R., Hughes, N., & Ziemba, D. (2018). The discipline that 'became': Developments in music technology in British higher education between 2007 and 2018. *Journal of Music Technology and Education, 11*(3), 251–267. https://doi.org/10.1386/jmte.11.3.251_1

Boon, E. (2018). Relation of culture and cognition: new pedagogical formulations in music education. *Journal of Human Sciences, 15*(3), 1–15. https://doi.org/10.14687/jhs.v15i3.5454

Boorom, O., Nayak, S., Ladányi, E., Magne, C., & Gordon, R. (2022). Music and developmental disorders of reading and spoken language. https://doi.org/10.31234/osf.io/r5t4c

Bourne, L., Goldstein, S., & Link, W. (1964). Concept learning as a function of availability of previously presented information. *Journal of Experimental Psychology*, *67*(5), 439-448. https://doi.org/10.1037/h0043205

Brattico, E. and Pearce, M. (2013). The neuroaesthetics of music. *Psychology of Aesthetics Creativity and the Arts*, *7*(1), 48-61. https://doi.org/10.1037/a0031624

Bugos, J. (2015). Greasing the skids of the musical mind. *General Music Today*, *29*(1), 5–11. https://doi.org/10.1177/1048371314566236

Butler, M. & Senior, C. (2007). Toward an organizational cognitive neuroscience. *Annals of the New York Academy of Sciences, 1118*(1), 1–17. https://doi.org/10.1196/annals.1412.009

Cahill, H. and Hovland, C. (1960). The role of memory in the acquisition of concepts. *Journal of Experimental Psychology, 59*(3), 137-144. https://doi.org/10.1037/h0041662

Cano, M., & Sanchez-Iborra, R. (2015). On the use of a multimedia platform for music education with handicapped children: A case study. *Computers & Education*, *87*, 254-276. https://doi.org/10.1016/j.compedu.2015.07.010

Collins, A. (2013). Music education and the brain. *Update Applications of Research in Music Education*, *32*(2), 4–10. https://doi.org/10.1177/8755123313502346

Collins, A. (2013). Neuroscience meets music education: Exploring the implications of neural processing models on music education practice. *International Journal of Music Education*, *31*(2), 217–231. https://doi.org/10.1177/0255761413483081

Costa-Giomi, E. (2014). The long-term effects of childhood music instruction on intelligence and general cognitive abilities. *Update Applications of Research in Music Education*, *33*(2), 20-26. https://doi.org/10.1177/8755123314540661

Csicsvari, J. and Dupret, D. (2014). Sharp wave/ripple network oscillations and learning-associated hippocampal maps. *Philosophical Transactions of the Royal Society B Biological Sciences, 369*(1635), 20120528. https://doi.org/10.1098/rstb.2012.0528

Curtis, L. & Fallin, J. (2014). Neuroeducation and music. *Music Educators Journal, 101*(2), 52–56. https://doi.org/10.1177/0027432114553637

Daikoku, T. (2018). Neurophysiological markers of statistical learning in music and language: hierarchy, entropy, and uncertainty. *Brain Sciences, 8*(6), 114. https://doi.org/10.3390/brainsci8060114

Dominowski, R. (1965). Role of memory in concept learning. *Psychological Bulletin, 63*(4), 271-280. https://doi.org/10.1037/h0021801

Doré, B., Zerubavel, N., & Ochsner, K. (2015). Social cognitive neuroscience: a review of core systems. https://doi.org/10.1037/14341-022

Dunbar-Hall, P., Rowley, J., Brooks, W., Cotton, H., & Lill, A. (2015). E-portfolios in music and other performing arts education: History through a critique of literature. *Journal of Historical Research in Music Education, 36*(2), 139–154. https://doi.org/10.1177/153660061503600205

Forster, M. (2014). Review of the aesthetic brain: how we evolved to desire beauty and enjoy art. *Psychology of Aesthetics Creativity and the Arts, 8*(2), 260–261. https://doi.org/10.1037/a0036401

Gage, N., Low, B., & Reyes, F. (2019). Listen to the tastemakers: Building an urban arts high school music curriculum. *Research Studies in Music Education, 42*(1), 19–36. https://doi.org/10.1177/1321103x19837758

Gerstner, J. and Yin, J. (2010). Circadian rhythms and memory formation. *Nature Reviews Neuroscience, 11*(8), 577-588. https://doi.org/10.1038/nrn2881

Gkintoni, E., Farmakopoulou, I., & Theodoratou, M. (2023). Neuromusic education in cognition and quality-of-life promotion an outline. *Technium Social Sciences Journal, 40*, 223–232. https://doi.org/10.47577/tssj.v40i1.8347

Gkintoni, E., Farmakopoulou, I., & Theodoratou, M. (2023). Neuromusic education in cognition and quality-of-life promotion: An outline. *Technium Social Sciences Journal, 40*, 223–232. https://doi.org/10.47577/tssj.v40i1.8347

Gong, W. (2020). Application of cognitive psychology in the music note cognition of exceptional children. *Revista Argentina De Clinica Psicologica.* https://doi.org/10.24205/03276716.2020.127

Gorbunova, I., & Михуткина, Н. (2020). Computer musical creative work in the Russian initial vocational education system. *Propósitos Y Representaciones, 8*(2). https://doi.org/10.20511/pyr2020.v8n2.523

Grahn, J. (2012). Neural mechanisms of rhythm perception: current findings and future perspectives. *Topics in Cognitive Science, 4*(4), 585–606. https://doi.org/10.1111/j.1756-8765.2012.01213.x

Grahn, J. (2012). See what I hear? Beat perception in auditory and visual rhythms. *Experimental Brain Research, 220*(1), 51–61. https://doi.org/10.1007/s00221-012-3114-8

Grahn, J., Henry, M., & McAuley, J. (2011). FMRI investigation of cross-modal interactions in beat perception: audition primes vision, but not vice versa. *Neuroimage, 54*(2), 1231-1243. https://doi.org/10.1016/j.neuroimage.2010.09.033

Gromko, J. and Poorman, A. (1998). The effect of music training on preschoolers' spatial-temporal task performance. *Journal of Research in Music Education, 46*(2), 173-181. https://doi.org/10.2307/3345621

Hallam, S. (2010). The power of music: its impact on the intellectual, social and personal development of children and young people. *International Journal of Music Education, 28*(3), 269–289. https://doi.org/10.1177/0255761410370658

Handayani, B., & Corebima, A. (2017). Model brain-based learning (bbl) and whole brain teaching (WBT) in learning. *International Journal of Science and Applied Science Conference Series, 1*(2), 153. https://doi.org/10.20961/ijsascs.v1i2.5142

Harvey, A. (2020). Links between the neurobiology of oxytocin and human musicality. *Frontiers in Human Neuroscience, 14*. https://doi.org/10.3389/fnhum.2020.00350

Haslbeck, F., Bucher, H., Bassler, D., & Hagmann, C. (2017). Creative music therapy to promote brain structure, function, and neurobehavioral outcomes in preterm infants: A randomized controlled pilot trial protocol. *Pilot and Feasibility Studies, 3*(1). https://doi.org/10.1186/s40814-017-0180-5

He, Y. (2016). Research of music talent cultivation based on practice education. https://doi.org/10.2991/icsshe-16.2016.106

Hegde, S. (2014). Music-based cognitive remediation therapy for patients with traumatic brain injury. *Frontiers in Neurology, 5*. https://doi.org/10.3389/fneur.2014.00034

Heng, G., Chai, Q., & Chen, S. (2021). Effects of familiarity with a musical style on music-evoked emotions: An EEG study. https://doi.org/10.31234/osf.io/vzny2

Herff, S., Olsen, K., Prince, J., & Dean, R. (2017). Interference in memory for pitch-only and rhythm-only sequences. *Musicae Scientiae, 22*(3), 344-361. https://doi.org/10.1177/1029864917695654

Hille, K., Gust, K., Bitz, U., & Kammer, T. (2011). Associations between music education, intelligence, and spelling ability in elementary school. *Advances in Cognitive Psychology, 7*(-1), 1-6. https://doi.org/10.2478/v10053-008-0082-4

Ho, Y., Cheung, M., & Chan, A. (2003). Music training improves verbal but not visual memory: Cross-sectional and longitudinal explorations in children. *Neuropsychology, 17*(3), 439-450. https://doi.org/10.1037/0894-4105.17.3.439

Hodges, D. (2009). Can neuroscience help us do a better job of teaching music? *General Music Today, 23*(2), 3–12. https://doi.org/10.1177/1048371309349569

Hodges, D., & Wilkins, R. (2015). How and why does music move us? *Music Educators Journal, 101*(4), 41–47. https://doi.org/10.1177/0027432115575755

Hodges, D., Hairston, W., & Burdette, J. (2005). Aspects of multisensory perception: The integration of visual and auditory information in musical experiences. *Annals of the New York Academy of Sciences, 1060*(1), 175–185. https://doi.org/10.1196/annals.1360.012

Hyde, K., Lerch, J., Norton, A., Forgeard, M., Winner, E., Evans, A., … & Schlaug, G. (2009). Musical training shapes structural brain development. *Journal of Neuroscience, 29*(10), 3019-3025. https://doi.org/10.1523/jneurosci.5118-08.2009

Jamieson, R., Crump, M., & Hannah, S. (2011). An instance theory of associative learning. *Learning & Behavior, 40*(1), 61–82. https://doi.org/10.3758/s13420-011-0046-2

Jaschke, A., Honing, H., & Scherder, E. (2018). Exposure to a musically-enriched environment; its relationship with executive functions, short-term memory and verbal IQ in primary school children. *Plos One, 13*(11), e0207265. https://doi.org/10.1371/journal.pone.0207265

Jaschke, A., Honing, H., & Scherder, E. (2018). Longitudinal analysis of music education on executive functions in primary school children. *Frontiers in Neuroscience, 12*. https://doi.org/10.3389/fnins.2018.00103

Johnson, C. (2017). Teaching music online: changing pedagogical approach when moving to the online environment. *London Review of Education, 15*(3). https://doi.org/10.18546/lre.15.3.08

Kim, J. (2020). From the body image to the body schema, from the proximal to the distal: embodied musical activity toward learning instrumental musical skills. *Frontiers in Psychology, 11*. https://doi.org/10.3389/fpsyg.2020.00101

Klann, E. & Sweatt, J. (2008). Altered protein synthesis is a trigger for long-term memory formation. *Neurobiology of Learning and Memory, 89*(3), 247–259. https://doi.org/10.1016/j.nlm.2007.08.009

Koelsch, S. (2009). A neuroscientific perspective on music therapy. *Annals of the New York Academy of Sciences, 1169*(1), 374–384. https://doi.org/10.1111/j.1749-6632.2009.04592.x

Korsakova-Kreyn, M. (2018). Two-level model of embodied cognition in music. *Psychomusicology Music Mind and Brain, 28*(4), 240-259. https://doi.org/10.1037/pmu0000228

Landau, A. and Limb, C. (2017). The neuroscience of improvisation. *Music Educators Journal, 103*(3), 27-33. https://doi.org/10.1177/0027432116687373

Lee, N. & Chamberlain, L. (2007). Neuroimaging and psychophysiological measurement in organizational research. *Annals of the New York Academy of Sciences, 1118*(1), 18–42. https://doi.org/10.1196/annals.1412.003

Leman, M., & Maes, P. (2015). The role of embodiment in the perception of music. *Empirical Musicology Review, 9*(3-4), 236-246. https://doi.org/10.18061/emr.v9i3-4.4498

Levenson, J., O'Riordan, K., Brown, K., Trinh, M., Molfese, D., & Sweatt, J. (2004). Regulation of histone acetylation during memory formation in the hippocampus. *Journal of Biological Chemistry, 279*(39), 40545–40559. https://doi.org/10.1074/jbc.m402229200

Levitin, D. and Tirovolas, A. (2009). Current advances in the cognitive neuroscience of music. *Annals of the New York Academy of Sciences, 1156*(1), 211-231. https://doi.org/10.1111/j.1749-6632.2009.04417.x

Li, H., Xu, W., Wang, D., Wang, L., Fang, Q., Wan, X., … & Cen, X. (2021). 4r tau modulates cocaine-associated memory through adult dorsal hippocampal neurogenesis. *Journal of Neuroscience, 41*(31), 6753–6774. https://doi.org/10.1523/jneurosci.2848-20.2021

Li, X., Yan, Y., Soraghan, J., Wang, Z., & Ren, J. (2022). A music cognition–guided framework for multi-pitch estimation. *Cognitive Computation, 15*(1), 23-35. https://doi.org/10.1007/s12559-022-10031-5

Li, Z. (2017). Design of online vocal music course based on Azure-PaaS platform. *International Journal of Emerging Technologies in Learning (IJET), 12*(09), 17. https://doi.org/10.3991/ijet.v12i09.7495

Lieberman, M. (2005). Principles, processes, and puzzles of social cognition: an introduction for the special issue on social cognitive neuroscience. *Neuroimage, 28*(4), 745-756. https://doi.org/10.1016/j.neuroimage.2005.07.028

Loui, P., Demorest, S., Pfordresher, P., & Iyer, J. (2015). Neurological and developmental approaches to poor pitch perception and production. *Annals of the New York Academy of Sciences, 1337*(1), 263–271. https://doi.org/10.1111/nyas.12623

Machfauzia, A., Djohan, D., & Sittiprapaporn, P. (2020). Intellectual character of metacognition in thinking strategies. *Asian Journal of Medical Sciences, 11*(1), 51-56. https://doi.org/10.3126/ajms.v11i1.26519

Markič, O. (2013). The philosophical framework for understanding neuroscientific research. *Interdisciplinary Description of Complex Systems, 11*(4), 351–362. https://doi.org/10.7906/indecs.11.4.1

Maryati, S., Purwanti, I., & Mubarika, M. (2020). The effect of brain based learning on improving students' critical thinking ability and self-regulated. *Ijis Edu Indonesian Journal of Integrated Science Education, 2*(2), 162. https://doi.org/10.29300/ijisedu.v2i2.3333

Mayer, R. (2010). Applying the science of learning to medical education. *Medical Education, 44*(6), 543–549. https://doi.org/10.1111/j.1365-2923.2010.03624.x

McCormack, B., & Klopper, C. (2016). The potential of music in promoting oracy in students with English as an additional language. *International Journal of Music Education, 34*(4), 416–432. https://doi.org/10.1177/0255761415619066

Miendlarzewska, E. and Trost, W. (2014). How musical training affects cognitive development: rhythm, reward and other modulating variables. *Frontiers in Neuroscience, 7.* https://doi.org/10.3389/fnins.2013.00279

Ng, B., & Ong, A. (2018). Neuroscience and digital learning environment in universities: What do current research tell us? *Journal of the Scholarship of Teaching and Learning, 18*(3). https://doi.org/10.14434/josotl.v18i3.22651

Okely, J., Deary, I., & Overy, K. (2021). The edinburgh lifetime musical experience questionnaire (elmeq): responses and non-musical correlates in the lothian birth cohort 1936. *Plos One, 16*(7), e0254176. https://doi.org/10.1371/journal.pone.0254176

Okely, J., Overy, K., & Deary, I. (2022). Experience of playing a musical instrument and lifetime change in general cognitive ability: evidence from the Lothian birth cohort 1936. *Psychological Science, 33*(9), 1495–1508. https://doi.org/10.1177/09567976221092726

Palmeri, T., Love, B., & Turner, B. (2017). Model-based cognitive neuroscience. *Journal of Mathematical Psychology, 76*, 59-64. https://doi.org/10.1016/j.jmp.2016.10.010

Peterson, A. (2011). The impact of neuroscience on music education advocacy and philosophy. *Arts Education Policy Review, 112*(4), 206–213. https://doi.org/10.1080/10632913.2011.592475

Piwowarski, M., Singh, U., & Nermend, K. (2019). The cognitive neuroscience methods in the analysis of the impact of advertisements in shaping people's health habits*. *European Research Studies Journal, XXII*(Issue 4), 457-471. https://doi.org/10.35808/ersj/1521

Platek, S. M., & Shackelford, T. K. (Eds.). (2009). Foundations in evolutionary cognitive neuroscience. Cambridge University Press. https://doi.org/10.1017/cbo9780511626586

Ramamurthy, U., Franklin, S., & Negatu, A. (1998). Learning concepts in software agents. https://doi.org/10.7551/mitpress/3119.003.0057

Ramón, L., Martinón-Torres, F., & Salas, A. (2021). Sensogenomics and the biological background underlying musical stimuli: perspectives for a new era of musical research. *Genes, 12*(9), 1454. https://doi.org/10.3390/genes12091454

Ren, F. (2019). Influence of cognitive neuroscience on contemporary philosophy of science. *Translational Neuroscience, 10*(1), 37–43. https://doi.org/10.1515/tnsci-2019-0007

Rosenboom, D. (2014). Active imaginative listening—a neuromusical critique. *Frontiers in Neuroscience, 8*. https://doi.org/10.3389/fnins.2014.00251

Sanchez, D. and Reber, P. (2013). Explicit pre-training instruction does not improve implicit perceptual-motor sequence learning. *Cognition, 126*(3), 341-351. https://doi.org/10.1016/j.cognition.2012.11.006

Schiavio, A., & Schyff, D. (2018). 4E music pedagogy and the principles of self-organisation. *Behavioral Sciences, 8*(8), 72. https://doi.org/10.3390/bs8080072

Schüler, A., Scheiter, K., & Genuchten, E. (2011). The role of working memory in multimedia instruction: is working memory working during learning from text and pictures? *Educational Psychology Review, 23*(3), 389-411. https://doi.org/10.1007/s10648-011-9168-5

Schweighofer, N., Lee, J., Goh, H., Choi, Y., Kim, S., Stewart, J., … & Winstein, C. (2011). Mechanisms of the contextual interference effect in individuals poststroke. *Journal of Neurophysiology, 106*(5), 2632-2641. https://doi.org/10.1152/jn.00399.2011

Sewell, J., Santhosh, L., & O'Sullivan, P. (2020). How do attending physicians describe cognitive overload among their workplace learners? *Medical Education, 54*(12), 1129–1136. https://doi.org/10.1111/medu.14289

Simon, S. (2014). Using longitudinal scales assessment for instrumental music students. *Music Educators Journal, 101*(1), 86–92. https://doi.org/10.1177/0027432114539704

Smedt, J. & Cruz, H. (2010). Toward an integrative approach of cognitive neuroscientific and evolutionary psychological studies of art. *Evolutionary Psychology, 8*(4), 147470491000800. https://doi.org/10.1177/147470491000800411

Soemer, A. (2015). The multicomponent working memory model, attention, and long-term memory in multimedia learning: a comment on schweppe and rummer (2014). *Educational Psychology Review, 28*(1), 197–200. https://doi.org/10.1007/s10648-015-9303-9

Soicher, R., Becker-Blease, K., & Bostwick, K. (2020). Adapting implementation science for higher education research: The systematic study of implementing evidence-based practices in college classrooms. *Cognitive Research Principles and Implications, 5*(1). https://doi.org/10.1186/s41235-020-00255-0

Suendarti, M., & Virgana, V. (2022). Elevating natural science learning results through music media and students' learning style. *Cypriot Journal of Educational Sciences, 17*(11), 4133-4147. https://doi.org/10.18844/cjes.v17i11.7560

Thaut, M. (2005). The future of music in therapy and medicine. *Annals of the New York Academy of Sciences, 1060*(1), 303–308. https://doi.org/10.1196/annals.1360.023

Thaut, M., Peterson, D., McIntosh, G., & Hoemberg, V. (2014). Music mnemonics aid verbal memory and induce learning are related brain plasticity in multiple sclerosis. *Frontiers in Human Neuroscience, 8*. https://doi.org/10.3389/fnhum.2014.00395

Tseng, Y., Liu, H., Liou, M., Tsai, A., Chien, V., Shyu, S., … & Yang, Z. (2019). Lingering sound: Event-related phase-amplitude coupling and phase-locking in fronto-temporo-parietal functional networks during memory retrieval of music melodies. *Frontiers in Human Neuroscience, 13*. https://doi.org/10.3389/fnhum.2019.00150

Verdi, B. (2022). Creating professional learning communities for music educators. *Music Educators Journal, 109*(2), 14–21. https://doi.org/10.1177/00274321221134790

Vila, F. (2018). Neurobiological foundations of music. *Anales Ranm, 135*(135(02)), 34-40. https://doi.org/10.32440/ar.2018.135.02.supl01.art03

Villamizar, C. (2021). The importance of music education in the development and performance of executive functions. https://doi.org/10.20944/preprints202102.0195.v1

Vuust, P., Gebauer, L., & Witek, M. (2014). Neural underpinnings of music: the polyrhythmic brain., 339-356. https://doi.org/10.1007/978-1-4939-1782-2_18

Weidner, B. (2020). A grounded theory of musical independence in the concert band. *Journal of Research in Music Education, 68*(1), 53–77. https://doi.org/10.1177/0022429419897616

Weinberger, N. (2014). Neuromusic research: Some benefits of incorporating basic research on the neurobiology of auditory learning and memory. *Frontiers in Systems Neuroscience, 7*. https://doi.org/10.3389/fnsys.2013.00128

Yang, M. (2018). Application of emotion cognitive model in interactive national music education. *Educational Sciences Theory & Practice.* https://doi.org/10.12738/estp.2018.6.182

Yi, W., Jeong, D., & Cho, J. (2014). Music perception as embodied cognition: Behavioral evidence of auditory cue effect. *Contemporary Engineering Sciences, 7*, 1215-1223. https://doi.org/10.12988/ces.2014.49151

Yu, L. (2018). Brain evoked potential analysis of effects of popular music training on adolescents' cognitive neurobehavioral plasticity. *Neuroquantology, 16*(5). https://doi.org/10.14704/nq.2018.16.5.1424

Zahn, R. (2009). The role of neuroimaging in translational cognitive neuroscience. *Topics in Magnetic Resonance Imaging, 20*(5), 279–289. https://doi.org/10.1097/rmr.0b013e3181e8f215

Zhu, Y., Wang, R., & Wang, Y. (2016). A comparative study of the impact of theta-burst and high-frequency stimulation on memory performance. *Frontiers in Human Neuroscience, 10*. https://doi.org/10.3389/fnhum.2016.00019

Zhuo, Y. and Leung, B. (2019). Music teachers and their implementation of the new music curriculum standards in China. *International Journal of Music Education, 37*(2), 178-197. https://doi.org/10.1177/0255761418820647

Zimmerman, E. & Lahav, A. (2012). The multisensory brain and its ability to learn music. *Annals of the New York Academy of Sciences, 1252*(1), 179–184. https://doi.org/10.1111/j.1749-6632.2012.06455.x

Zuk, J. and Gaab, N. (2018). Evaluating predisposition and training in shaping the musician's brain: the need for a developmental perspective. *Annals of the New York Academy of Sciences, 1423*(1), 40-50. https://doi.org/10.1111/nyas.13737

Author Contributions

The article is single-authored.

Conflict of Interest

The authors have declared no conflict of interest in this study.

Funding

The authors did not receive any funding for this article from any institution.

Note

This is a compilation work. The author has provided the declaration.