The Effects of Music on Different Cognitive Performances

Sijia Wang[1, *]

[1] Department of Psychological & Brain Science, University of California, Santa Barbara, California, USA

*Corresponding author: sijia_wang@ucsb.edu

Abstract. This article aims to review studies about the influences of music on cognitive performances and consider the potential mediators that contribute to this association. Much previous research was devoted to studying the influences of music on cognitive performances and obtained opposite results. As these studies showed contradictory findings, it is imperative to reconcile the contradiction to boost the understanding of the effects of music and decide whether to apply it to the clinical setting. Several potential factors were examined in the previous studies, like the types of tasks, music genres, and individual differences with corresponding strategies regarding music usage during cognitive performances. In this study, factors like motivation, emotion, and stress reduction are emphasized and incorporated into those factors to eliminate the discrepancy of results obtained by the previous studies about the influences of music on performance outcomes. Instead of discussing each factor separately from others, a multidimensional approach—considering multiple factors together to measure the overall benefits and impairments that the factors brought, as well as to evaluate the final effects of music—is recommended, and future studies are needed.

Keywords: the effects of music; cognitive performances; music therapy.

1. Introduction

Music is“vocal, instrumental, or mechanical sounds” with three characteristics: rhythm, melody, and harmony [1], popular among modern city dwellers. According to Statista online data, 51% of 1005 respondents in the survey reported an everyday music listening frequency. Music has also become an increasingly accepted choice by people while engaging in other tasks. Accordingly, researchers try to find the influence of music on listeners' performances, especially cognitive performances. However, contradictory findings presented below have been revealed regarding the impacts of background music (BGM) on cognitive performances. This study compares different related research by metanalysis and tries to reconcile the contradictions by systematically considering the potential mediators.

2. The Mozart Effect: Enhancement of Spatial Performance

One of the most typical examples of the impacts of music on cognitive performance is the Mozart effect. The Mozart effect is the improvement in spatial performance following exposure to Mozart's compositions (but not limited to Mozart's music). It is well-known and attracts many investigators, but Rauscher and his colleagues first proposed it. They tested the causal relationship between music cognition and spatial performance, choosing Mozart's sonata as the music type and the Stanford-Binet intelligence scale as the measurement for spatial performance. The result revealed that participants listening to Mozart's sonata for 10 minutes had a higher IQ than participants in the relaxation and silence group [2].

Rauscher and his colleagues further supported the Mozart effect by elucidating the potential underlying mechanisms: music listening might enhance the neuron firing in the higher cortical areas by priming or exercising the patterns also responsible for other cognitive performances like spatial-temporal reasoning [3]. Therefore, music might prime the neurobiological ability for cognitive performances.

In addition, Xing and his colleagues conducted an animal experiment to test the association between Mozart music and spatial learning by examining the impacts of Mozart music on the levels of brain-derived neurotrophic factor (BDNF) and its receptors tyrosine receptor kinase B (TrkB) in the subregions in the hippocampus. The results suggested that rats who received Mozart's piano sonata exposure in the postnatal period had better spatial performance in the Morris water maze, a test created for spatial learning and memory. A higher BDNF and TrkB protein expression in dorsal hippocampus CA3 and dentate gyrus compared to the rats who did not receive the exposure [4]. As BDNF and TrkB play a role in supporting survival, differentiation, and functions of neurons, and the dorsal hippocampus and dentate gyrus are essential for spatial information processing and memory, the benefits of music are demonstrated in terms of neurobiological improvement. The biological changes brought by music were also found in other studies utilizing other animal models and types of music [5-7].

However, while several studies showed that a specific Mozart piano sonata was able to improve the spatial-temporal reasoning ability of participants, and a similar effect was also replicated by using other similarly complex music, other researchers could not replicate the results, which results in ambiguity and confusion in the field of music psychology [8], albeit those mentioned above convincing biological evidence. Also, the same dilemma appears in the relationship between background music listening and other cognitive performances.

3. The Effects of Music on Other Cognitive Performances

3.1 Types of Cognitive Tasks

Beyond the Mozart effect, enormous research showed the effects of music on diverse cognitive tasks. For example, Perham and Currie found that background music (BGM) could lead to worse performance on reading comprehension [9]. At the same time, Mammarella et al. reported an enhancing effect of BGM on phonological working memory capacity [10]. Comparable amounts of studies supported both the positive and negative effects of BGM. Goltz and Sadakata explained this contradiction by exploring the types of performance that potentially modulate the association between listening to music and task performance outcomes. Specifically, five cognitive tasks were examined separately–reading, memory, critical thinking and reasoning, writing, and attention. While reading and memory were shown to be impaired by the BGM, attention was improved by the BGM [11]. Thus, types of cognitive tasks potentially contribute to the discrepancy in the effects of BGM.

Accordingly, the underlying mechanisms of each cognitive task might modulate the effects of BGM. As different cognitive tasks require different types and levels of cognitive resources like attention, executive control, and working memory and activate different networks and pathways in the brain regions, the overall disparity in these cognitive tasks might lead to the discrepancy in the results of the effects of BGM or music found by the studies above.

In addition, a negative result might be caused by an interference effect resulting from an overload of processing capacity. That is if the cognitive task requires the same cognitive resources as the music listening. They might confront a competition for resources, and an overload of processing capacity will be caused. Indeed, Goltz and Sadakata suggested that listening to lyrics in a familiar language led to more severe impairment of memory performance [11].

3.2 Music Genres

But the influences of preceding factors might interact with the types of music. Research revealed the different impacts of various music genres on cognitive performance. On the one hand, Rickard, Toukhsati, and Field summarized several related experiments, showing that different types of music, including calming background music, background classical music, rock music, and Vivaldi's Four Seasons (Winter), have an improving effect on cognitive tasks such as arithmetic performance, category fluency tasks, reading comprehension, and spatial performance [8]. On the other hand, Crawford and Strapp revealed an impairment caused by both vocal and instrumental music, and vocal music has a more adverse effect [12]. The results of the findings agreed on the existence of the effects of music but diverged on whether the effects were positive or negative.

The predicament is exacerbated by a similar discrepancy in research results caused by the types of cognitive tasks. While Ferreri and Verga reported consistent impairments of BGM on memory and reading [13], Borella et al. demonstrated a positive effect [14]. Also applied to the studies on the Mozart effect, strictly replicated experiments did not generate a consistent result.

3.3 Individual Differences

Goltz and Sadakata then considered the underlying individual differences behind BGM usage during the cognitive tasks as a mediator of the association to reconcile the disparity. Specifically, individuals' cognitive performances are divergently benefited or impaired by music in terms of personal factors like age, personality types, habits, and living environments. Goltz and Sadakata further assumed that people voluntarily develop specific strategies for BGM usage based on their factors to boost performance. Accordingly, Goltz and Sadakata conducted survey studies to compare the individual differences regarding BGM usage during cognitive tasks and aimed to find the potential factors that modulate the effects of music on performance outcomes. The study concluded that individual differences like age, attitudes toward music effects on performance, and personality (extroverts vs. introverts) might interact with the types of tasks and the levels of task difficulties to influence individuals' decisions about music listening during cognitive tasks and modulate the outcomes of performance [11].

More specifically, young participants are likely to use BGM more frequently than their older counterparts; participants who believe a positive impact of BGM usage on cognitive performance also tend to use BGM more frequently [11]. But no correlation between personality type and BGM use was found in this study [11], while other research stressed the importance of personality types (extroversion vs. introversion) in explaining the contradictory effects of music [15-16]. The study made an enormous contribution to presenting an insight into the effects of music on cognitive performances by considering the individual variances. Even though the study recruited a significant sample size, the study utilized a relatively subjective survey method and conducted the research based on an assumption, which led to some limitations.

On the contrary, even if the credibility of the premise of Goltz's and Sadakata's study was enhanced by the finding of the negative correlation between task difficulty and the frequency of BGM usage, the participants showed music listening preference in reading tasks. In contrast, the results of studies presented impairments caused by BGM on reading comprehension [11]. This decreases the credibility of the hypothesis that individuals would employ ideal music listening strategies to boost their performance outcomes.

As a result, future studies should conduct experiments to test individual differences rather than correlational studies to further (or weaken) the contribution of individual differences to the association. In addition, factors other than the abovementioned can be considered in impacting the individuals' strategies and cognitive performances.

4. Neurobiology, Motivation, Emotion, and Stress Reduction

4.1Neurobiology of Music: the Reward Pathway and Motivation

Chanda and Levitin claimed that music could trigger reward pathways by acting on dopamine and the opioid system. The article reviewed related experiments and argued that listening to pleasurable music can increase the regional cerebral blood flow of brain regions that participate in reward and reinforcement, like the nucleus accumbens–part of the mesolimbic pathway in the dopaminergic system. Also, music listening would lead to an increased amount of neurotransmitters like dopamine–playing a role in reward experiences and cognitive and behavioral functions–and opioid peptides, responsible for pain relief and euphoria [17]. As reward systems are involved in motivational processes, music might influence individuals' motivation to engage in cognitive performances and thus result in a better performance outcome.

Furthermore, motivation can be increased by the reduced workload of the prefrontal cortex. The PFC showed significantly reduced activity when participants did the memory test for words encoded with the BGM [18]. It implied that music could mitigate the resource demand of the task. Also, music might enhance individuals' self-confidence and thus modulate the perception of task difficulty [19], and task difficulty is directly correlated to motivations [20].

4.2 Emotion and Stress Reduction

In addition to motivation, emotions which play a role in affecting motivation potentially modulate the association between music and the outcomes of cognitive performances.

Ferreri and his colleagues suggested that pleasure–one of the dimensions of emotions–induced by music listening might rely on the dopaminergic system and be responsible for modulating motivation [21]. Indeed, several studies demonstrated the relationship between emotion and motivation [22]. Lang argued that emotions could be considered"motivationally tuned states of readiness" [23]. Accordingly, emotions might not only affect the performance outcomes directly but also participate in improving motivation for cognitive tasks.

Researchers found that music could elicit emotions[24]. Specifically, it argued that the way that music can evoke emotions is through cognitive appraisals. Based on appraisal theorists, cognitive appraisals basically state the emotions elicited by the music through evaluations of the music. For example, if the person thinks the music is excellent and likes it, then a positive emotion is generated, and vice versa. Or individuals might evaluate what emotions the music expresses and label "happiness" and "sadness" to the music itself [24].

Additionally, Juslin and Västfjäll argued that music could induce emotions directly and proposed six mechanisms other than cognitive appraisals to explain how music (and other stimuli) induce emotion [24]. Accordingly, it is undeniable that music can elicit emotions, and the pathways might be diverse.

Moreover, the Arousal Mood Hypothesis might be a candidate to explain the possible underlying mechanisms of how music-induced emotions affect participants' performance outcomes other than the motivation discussed above. It supports arousal and mood as two mediators of this association. Goltz and Sadakata claimed that pleasant or stimulant music could induce positive moods like pleasure/happiness and increase one's arousal levels to optimize people's performance, and vice versa [11]. Also, it could reconcile the partial contradiction of the music effects: over-arousal of individuals triggered by the music can lead to an opposite direction that causes impairments on one's performance [11]. This might explain why some types of pleasant music can improve performance outcomes while others do not.

Indeed, several studies support the Arousal Mood Hypothesis. Dosseville and his colleagues found that classical music might be able to elicit positive affect and improve multiple-choice test performance following a lecture [25]. Proverbio et al. demonstrated that the emotionally touching music listening group participants performed better on a facial memory test [26]. Goltz and Sadakata further support the emotion-inducing function of music by showing that mood improvement was at the top of the ranking of the reasons for BGM usage [11].

In addition, Berger and Schneck further claimed that music could regulate people's deviant homeostasis through "sub-cortical, non-cognitive pathways," which are innate to humans' physiological response mechanisms and, in turn, mitigate the stress levels, providing biological support to the impacts of music on individuals' physiology and psychology, like emotions [1].

Thus, this also might be one of the pathways that the BGM can lead to improving cognitive performance–by reducing stress levels. Davis and Thaut strengthened this association by demonstrating the physiological evidence of changes such as vascular constriction, heart rate, and so on following music listening, indicating a decreased anxiety and increased relationship from pre to post-test conditions [19]. The aforementioned increased amounts of neurotransmitters, opioid peptides, also might contribute to stress mitigation [17]. Chanda and Levitin also claimed that deactivation of the hippocampus was observed and might impact the hypothalamic-pituitary-adrenal axis (HPA), which regulates the release of stress hormones cortisol [17]. This stress-reduced function of music can potentially explain the obscure findings of Larsen and his colleagues' study, which revealed that sad-sounding music could induce a higher level of mixed feelings of happiness and sadness compared to happy-sounding music [26, 27]. Aligning with the stress-reduced function, in one way, sad-sounding music can prime sadness in individuals; in another way, sad-sounding music can ameliorate individuals' existing stress or negative emotions through transcendence or distraction, so that elicits positive emotions like happiness.

In conclusion, music-induced emotion and stress release is promising mediators for the association between music and the outcomes of cognitive performances. Based on the above discussion, many studies provide biological and empirical evidence to support the functions of music and the pathways that lead to the final performance outcomes.

5. Clinical Implications: Music Therapy

Studying music's effects on cognitive tasks has several clinical implications, like utilizing it as part of psychotherapy because of its influences on emotions and motivations. Indeed, abundant studies showed music therapy's positive effects in treating mental disorders [1, 28-30]. De l'Etoile demonstrated a beneficial effect of short-term music therapy on the treatment outcomes for adults with chronic mental illnesses like anxiety, obsessive-compulsive, somatization, etc. [28]. Edwards assessed 19 studies related to music therapy and concluded that music therapy as an auxiliary intervention to the standard treatment for clients with psychopathology could improve the overall outcomes of the treatment [29]. The metanalysis done by Solanki et al. further strengthened the argument above by showing the promising and positive effects of music therapy on psychosis and schizophrenia [30].

As "loss of interest in nearly all activities" is a symptom of major depressive disorder classified by DSM-5, it is reasonable to speculate that people diagnosed with MDD might lose the motivation to seek help or be resistant to psychotherapy. This conjecture was supported by several studies [29, 31]. The studies also showed that people with MDD reported high interpersonal distress, social avoidance [31], and difficulty feeling expression [29]. According to the abovementioned positive effects of music on regulating individuals' emotions and behaviors, it is highly possible that music can improve the symptoms of patients with MDD by increasing motivation to seek treatments, ameliorating depressive and stress levels, and strengthening feeling expression.

In addition, Hsu and Lai pointed out that depression was strongly associated with using alternative therapies [32]. Dinger et al. demonstrated that higher levels of interpersonal distress are correlated with a poorer therapeutic alliance and a higher rate of premature termination of therapy [31]. Renner et al. also found a negative association between the high levels of interpersonal distress and the outcomes of cognitive therapy [33]. Thus, if the effects of music can ease depression and stress levels, then an ideal treatment could be predicted because of a more closely bonded therapeutic relationship, a lower inclination of premature termination, and a better treatment outcome.

Therefore, the effects of music are worth future study as it has apparent clinical implications.

6. Conclusion

After systematically reviewing the contributions of types of cognitive tasks, music genre, and individual differences to the music–cognitive performances association from other research, it is necessary and imperative to emphasize the importance of factors like motivations, emotions, and stress reduction as modulators associating the effects of music with the outcomes of cognitive performances and incorporate them into examing the individuals' strategies regarding of music used during cognitive tasks, in addition to task types, and levels of task difficulties, etc.

As the mediating roles of those factors in the relationship between music and performance outcomes were clearly demonstrated and examined separately in enormous studies, the interactions among the factors above should be considered to be further examined to explain the discrepancy in results obtained by the previous music studies. For instance, Goltz and Sadakata found that although studies revealed the impairment caused by BGM on reading comprehension, the participants showed music listening preference in the reading tasks. This could be potentially explained by the stress-reduced function of music listening. That is, even though music listening might be impaired due to the competition for attention between two tasks, a higher level of stress or a lower level of motivation can have a more detrimental effect on reading comprehension than music listening. As music can alleviate stress and boost motivation, as discussed above, the improvement afterward might outweigh the impairment caused by the distraction brought by the music. An enhancement in performance will result in this situation. Thus, multiple factors should be considered to calculate the overall benefits and impairments brought by the factors on the music–cognitive performance association and evaluate the individual's strategies regarding BGM usage during cognitive tasks and the final effects of music.

As a result, it is a promising way to employ a multidimensional approach–considering multiple factors together–to evaluate the effects of music on cognitive performances. Future studies might be required to control all of the abovementioned variables except for the target factor if only one factor is focused on and examined in the experiment. On the other hand, a deeper insight into the effects of music is possibly obtained by using the multidimensional approach.

References

[1] Berger, D. Schneck D. The use of music therapy as a clinical intervention for physiologic functional adaptation. Journal of Scientific Exploration : a Publication of the Society for Scientific Exploration, 2003,17(4): 687-703.

[2] Rauscher F. H., Shaw G. L., Ky, C. N. Music and spatial task performance. Nature, 1993, 365(6447): 611-611.

[3] Rauscher F. H, Shaw G. L., Ky K. N. Listening to Mozart enhances spatial-temporal reasoning: towards a neurophysiological basis. Neuroscience letters, 1995, 185(1): 44-47.

[4] Xing Y., Chen W., Wang Y. Music exposure improves spatial cognition by enhancing the BDNF level of dorsal hippocampal subregions in the developing rats. Brain research bulletin, 2016, 121: 131-137.

[5] Chikahisa S., Sei H., Morishima, M. Exposure to music in the perinatal period enhances learning performance and alters BDNF/TrkB signaling in mice as adults. Behavioural brain research, 2006, 169(2): 312-319.

[6] Kim H., Lee M. H., Chang H. K. Influence of prenatal noise and music on the spatial memory and neurogenesis in the hippocampus of developing rats. Brain and Development, 2006, 28(2): 109-114.

[7] Panicker H., Wadhwa S., Roy T. S. Effect of prenatal sound stimulation on medio-rostral neostriatum/hyperstriatum ventrale region of chick forebrain: a morphometric and immunohistochemical study. Journal of Chemical Neuroanatomy, 2002, 24(2): 127-135.

[8] Rickard N. S., Toukhsati S. R., Field S. E., The effect of music on cognitive performance: Insight from neurobiological and animal studies. Behavioral and cognitive neuroscience reviews, 2005, 4(4): 235-261.

[9] Perham N., Currie H. Does listening to preferred music improve reading comprehension performance?. 2022.

[10] Mammarella N., Fairfield B., Cornoldi C. Does music enhance cognitive performance in healthy older adults? The Vivaldi effect. Aging clinical and experimental research, 2007, 19(5): 394-399.

[11] Goltz F., Sadakata M. Do you listen to music while studying? A portrait of how people use music to optimize their cognitive performance. Acta Psychologica, 2021, 220: 103417.

[12] Crawford H. J., Strapp C. M. Effects of vocal and instrumental music on visuospatial and verbal performance as moderated by studying preference and personality. Personality and individual differences, 1994, 16(2): 237-245.

[13] Ferreri L., Verga L. Benefits of music on verbal learning and memory: How and when does it work?. Music Perception: An Interdisciplinary Journal, 2016, 34(2): 167-182.

[14] Borella E., Carretti B., Meneghetti C. Is working memory training in older adults sensitive to music?. Psychological Research, 2019, 83(6): 1107-1123.

[15] Furnham A., Trew, S., Sneade, I. The distracting effects of vocal and instrumental music on the cognitive test performance of introverts and extraverts. Personality and Individual Differences, 1999, 27, 381–392.

[16] Furnham A., Strbac L. Music is as distracting as noise: The differential distraction of background music and noise on the cognitive test performance of introverts and extraverts. Ergonomics, 2002, 45(3), 203–217.

[17] Chanda M. L., Levitin D. J. The neurochemistry of music. Trends in cognitive sciences, 2013, 17(4): 179-193.

[18] Ferreri L., Bigand E., Perrey S. Less effort, better results: how does music act on prefrontal cortex in older adults during verbal encoding? An fNIRS study. Frontiers in human neuroscience, 2014, 8: 301.

[19] Davis W. B., Thaut M. H. The influence of preferred relaxing music on measures of state anxiety, relaxation, and physiological responses. Journal of music therapy, 1989, 26(4): 168-187.

[20] Britt T. W. The effects of identity-relevance and task difficulty on task motivation, stress, and performance. Motivation and emotion, 2005, 29(3): 189-202.

[21] Ferreri L., Mas-Herrero E., Zatorre R. J. Dopamine modulates the reward experiences elicited by music. Proceedings of the National Academy of Sciences, 2019, 116(9): 3793-3798.

[22] Hebb D., O. The organization of behavior: a neuropsychological theory. Science editions, 1949.

[23] Lang P., J. The emotion probe: Studies of motivation and attention. American psychologist, 1995, 50(5): 372.

[24] Hunter P., G, Schellenberg E G. Music and emotion[M]//Music perception. Springer, New York, NY, 2010: 129-164.

[25] Dosseville F., Laborde S., Scelles N. Music during lectures: Will students learn better?. Learning and Individual Differences, 2012, 22(2): 258-262.

[26] Mado Proverbio A., Lozano Nasi V., Alessandra Arcari L. The effect of background music on episodic memory and autonomic responses: listening to emotionally touching music enhances facial memory capacity. Scientific reports, 2015, 5(1): 1-13.

[27] Larsen J. T, Norris C. J, McGraw A. P. The evaluative space grid: a single-item measure of positivity and negativity. Cognition and Emotion, 2009, 23(3): 453-480.

[28] de l'Etoile S., K. The effectiveness of music therapy in group psychotherapy for adults with mental illness. The Arts in Psychotherapy, 2002, 29(2): 69-78.

[29] Edwards J. Music therapy in the treatment and management of mental disorders. Irish Journal of Psychological Medicine, 2006, 23(1): 33-35.

[30] Solanki M. S., Zafar M., Rastogi R. Music as a therapy: role in psychiatry. Asian Journal of Psychiatry, 2013, 6(3): 193-199.

[31] Dinger U., Zilcha-Mano S., McCarthy K. S., Barrett, M. S., Barber, J. P. Interpersonal problems as predictors of alliance, symptomatic improvement and premature termination in treatment of depression. Journal of Affective Disorders, 2013, 151(2): 800-803.

[32] Hsu, W., Lai, H. Effects of music on major depression in psychiatric inpatients. Archives of Psychiatric Nursing, 2004, 18(5): 193-199.

[33] Renner F., Jarrett R. B., Vittengl J. R., Barrett M. S., Clark L. A., Thase M. E. Interpersonal problems as predictors of therapeutic alliance and symptom improvement in cognitive therapy for depression. Journal of Affective Disorders, 2012, 138(3): 458–467.