Does Music Listening Facilitate Cognitive Processing? Past Controversies and a Novel Interpretation from the Attention Network Theory Perspective

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Abstract

Extensive research has demonstrated that music listening can either enhance or impair individuals' task performance. Researchers have proposed multiple theoretical hypotheses centered on pathways such as emotional experience and cognitive resource regulation, yet significant disagreements persist regarding the underlying mechanisms. Building upon a review of existing research and theories, this paper proposes an integrated explanatory framework for how music listening modulates cognitive processing. The core assumptions of this framework include: the attention system serves as a key cognitive hub through which music influences cognitive processing; both pre-task music and background music can act upon the three sub-networks of the brain' s attention network—alerting, orienting, and executive control—with potentially differential modulatory effects on executive control; furthermore, factors such as emotional arousal level and cognitive load can further modulate the direction and magnitude of music listening effects. Re-examining music listening effects from the perspective of attention network theory in cognitive neuroscience not only helps integrate and reconcile conflicts among existing mechanistic explanations, but also provides mechanistic guidance and theoretical support for clinical interventions, music applications in educational contexts, and the design of intelligent acoustic environments.

Full Text

Does Music Listening Facilitate Cognitive Processing? Revisiting Previous Debates from an Attention Network Perspective

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Abstract

A substantial body of research demonstrates that music listening can either enhance or impair individuals' task performance. Researchers have proposed various theoretical hypotheses centered on pathways such as emotional experience and cognitive resource regulation, yet significant disagreements persist regarding the underlying mechanisms. Building upon a systematic review of existing research and theories, this article proposes an integrative explanatory framework for how music listening modulates cognitive processing. The core assumptions of this framework are: (1) the attention system serves as a key cognitive hub through which music influences cognitive processing; (2) both advance music and background music can act upon the three sub-networks of the brain' s attention network—alerting, orienting, and executive control—with potentially divergent effects on executive control; and (3) factors such as emotional arousal level and cognitive load can further modulate the direction and magnitude of music listening effects. Re-examining music listening effects through the lens of cognitive neuroscience' s attention network theory not only helps integrate and reconcile existing conflicts in mechanistic explanations but also provides mechanistic guidance and theoretical support for clinical interventions, educational applications of music, and the design of intelligent acoustic environments.

Keywords: music listening effect, attention network theory, background music, advance music, emotional experience

From ancient Greek philosophical speculation about "music's power to cultivate the mind" to modern cognitive neuroscience' s exploration of music processing mechanisms, music psychology has undergone a profound transformation from metaphysical conjecture to empirical investigation. In recent years, as music has been widely applied in educational, clinical, and workplace contexts, the extent to which and the mechanisms through which music listening influences human cognitive processing have gradually become a focal point of research. The "music listening effect"refers to the modulatory impact that music, as an external input, exerts on non-musical cognitive functions such as attention, memory, and reasoning through the psychological state changes it triggers during or after listening (Gonzalez & Aiello, 2019). This reveals that music' s influence on cognition extends far beyond its physical acoustic properties (Patel & Iversen, 2014), instead depending deeply on the emotional arousal states it evokes, the reallocation of cognitive resources, and even direct modulation of central nervous system activity (Mendes et al., 2021; Patel, 2008).

Through systematic literature review, we identify three major challenges currently facing research on music listening effects: First, advance music and background music are often examined separately due to their different temporal structures, lacking a unified cross-paradigm integrative framework. Second, existing theories show significant divergence in their proposed modulatory pathways, with mechanisms related to emotional arousal, cognitive load, and neural activation failing to be integrated into a unified model. Third, although the attention system is widely recognized as a core hub through which music-induced state changes affect cognitive performance, its specific functional differentiation and modulatory pathways remain unclear. Addressing these issues, this article employs the attention network theory from cognitive neuroscience (Posner & Petersen, 1990) to construct a multi-level modulatory pathway wherein "music-induced state changes first regulate the processing efficiency of attention networks, which in turn broadly influences cognitive functions." This model focuses on two core issues: (1) the similarities and differences in the mechanisms through which different forms of music listening induce state changes such as emotional arousal and resource occupation; and (2) how these state changes differentially modulate attention sub-networks and subsequently affect specific manifestations of cognitive function.

1. The Double-Edged Sword Effect of Music Listening

Despite music being a highly complex and context-sensitive stimulus whose role in cognitive processing has long received widespread attention, its functional effects remain controversial. Music listening can either facilitate or interfere with cognitive processing, exhibiting a typical "double-edged sword" characteristic. This high inconsistency in effect direction and magnitude exists not only in laboratory studies (Kämpfe et al., 2011) but also extends to real-world clinical contexts (Gao et al., 2024; Sesso & Sicca, 2020). This phenomenon reveals disagreements that are reflected not only in contradictory experimental results but also in the fragmentation and opposition between theoretical hypotheses.

1.1 Contradictory Empirical Findings

On one hand, substantial evidence demonstrates that music listening can effectively enhance individuals' cognitive task performance. The most classic example is Rauscher et al.' s (1993) finding that listening to Mozart' s K.448 sonata before performing spatial reasoning tasks significantly improves performance. Although the replicability of the "Mozart effect"has been heavily debated (Pietschnig et al., 2010), its revealed positive effects of advance music have been corroborated in various forms in subsequent research. For instance, similar facilitative effects have been observed in spatial tasks such as paper folding and cutting, paper-and-pencil mazes (Xing et al., 2016), and mental rotation (Aheadi et al., 2010). This phenomenon has been demonstrated in children, older adults, and individuals with cognitive impairments (Cacciafesta et al., 2010; Gonzalez et al., 2003). Functional near-infrared spectroscopy (fNIRS) results reveal that brain regions activated by listening to Mozart' s music align with those involved in spatial localization and spatial reasoning (Jaušovec et al., 2006), suggesting specific gains for spatial cognition. Furthermore, background music also facilitates a broader range of cognitive performances including memory (Eskine et al., 2020; Smith et al., 2010), creativity (Eskine et al., 2020; He et al., 2017), verbal reasoning (Roth & Smith, 2008), and motor control (Angel et al., 2010) (Mendes et al., 2021). In episodic memory, for example, background music with positive emotional valence enhances memory effects in both adults (Ferreri et al., 2013) and older adults (Bottiroli et al., 2014; Ferreri et al., 2014). fNIRS studies further reveal that music may optimize resource allocation by activating the executive control network of the dorsolateral prefrontal cortex (DLPFC), thereby improving processing efficiency during the encoding phase (Ferreri et al., 2013, 2014).

On the other hand, numerous studies report significant interference effects of music listening on cognitive processing. Meta-analytic studies of the "Mozart effect" suggest its facilitative effects lack universality, possibly being limited to non-musician populations (Aheadi et al., 2010) or effective only under specific testing conditions (Carstens et al., 1995). For background music, evidence of negative effects is more prominent. In the domain of working memory, Salamé and Baddeley' s (1989) classic experiment found that background music severely impairs performance on digit span tasks, with this interference effect being particularly pronounced when musical rhythm and melody change frequently (Schweppe & Knigge, 2020). Researchers generally believe this may result from cross-modal resource competition between music (especially music with lyrics) and verbal tasks, which jointly occupy the phonological loop (Alley & Greene, 2008). Therefore, music interference may not directly impair memory storage but rather reduce working memory capacity by occupying attentional resources relied upon by the executive control network (Baddeley, 2012). Similar interference effects appear in free recall and recognition tasks, where listening to background music significantly reduces the number of words individuals can recall (Nguyen & Grahn, 2017). This complexity even extends to clinical practices such as music therapy (Sesso & Sicca, 2020). For example, in epilepsy treatment, music therapy may produce either anticonvulsive effects or proconvulsive responses (Gao et al., 2024).

Further research has examined which moderating variables influence the cognitive effects of music listening. Studies have found that background music' s effects on long-term memory retrieval show clear context-dependent effects: when background music during encoding and retrieval phases is consistent, recall performance significantly improves (Smith, 1985); when musical emotional valence matches the valence of learning materials, memory retrieval efficiency is also higher (Balch et al., 1992). This process may depend on the emotional memory circuit between the amygdala and hippocampus (Eschrich et al., 2008). In creativity, background music with positive emotional valence broadens attentional scope and improves performance on remote association tasks (Benedek et al., 2014); individuals with musical training show particularly outstanding performance on creativity tasks (Zhao, 2024). Ritter et al. (2017) further revealed that while positive music enhances divergent thinking, it has no significant effect on logical reasoning; conversely, negative music impairs divergent thinking but may improve performance on detail-processing tasks.

1.2 Divergent Theoretical Explanations and Their Limitations

To explain these contradictory "double-edged sword" phenomena, researchers have proposed two core theoretical hypotheses: the Mood-Arousal Hypothesis and the Limited Capacity Theory. The former emphasizes music' s activation and regulation of emotional and arousal states, while the latter focuses on music' s competitive impact on cognitive resources as an external, additional stimulus.

The Mood-Arousal Hypothesis has been widely used to explain facilitative effects in the "Mozart effect" (Roth & Smith, 2008; Thompson et al., 2001). This theory posits that music indirectly promotes attention and other cognitive functions by enhancing individuals' positive mood and subjective arousal levels (Mendes et al., 2021). This view receives support from fNIRS evidence: listening to Mozart' s music not only enhances brain networks closely related to spatial working memory and mental rotation tasks, but activation levels also correlate significantly with subjective pleasantness ratings (Jaušovec et al., 2006). However, the Mood-Arousal Hypothesis is primarily based on contexts involving advance music and has limited explanatory power for background music.

From the perspective of temporal sequence between music and cognitive tasks, advance music refers to music listening activities that occur before or during intervals between cognitive tasks, whereas background music is played while performing cognitive tasks. Therefore, the impact of background and advance music on individuals' cognitive processes may differ due to their temporal relationship with the task. Specifically, the listening effect of advance music typically manifests with a delay, which to some extent ensures the 发挥 of its facilitative effects. However, how long this effect persists and the extent to which it can actually influence subsequent cognitive tasks remain to be further verified (Thompson et al., 2001). In contrast, the listening effect of background music acts in real-time on current cognitive activities, with potentially more complex interactions between the two (Thompson et al., 2012), the most direct result being increased perceptual load.

Based on Kahneman' s (1973) Limited Capacity Theory, individuals' cognitive resources are limited; processing background music simultaneously while performing cognitive tasks may increase perceptual and executive load, thereby leading to decreased task performance (Lavie, 1995). Therefore, music listening may adversely affect cognitive processing under certain conditions, particularly when performing cognitive tasks requiring high attentional control (Kämpfe et al., 2011). Cognitive Load Theory further suggests that the complexity of external stimuli may induce different types of cognitive load (Lavie, 1995). Research has indicated that lyrics, rhythmic changes, or individuals' active listening tendencies may all exacerbate resource competition (Jeong et al., 2018; Shih et al., 2012). Some researchers believe that background music' s complex effects on simultaneously performed cognitive tasks may result from either increased perceptual load due to passive music processing or from individuals' active engagement in the listening process (Ding et al., 2024; Jeong et al., 2018). This also aligns with assumptions of Cognitive Load Theory (Lavie, 2005).

To reconcile the contradiction between music' s positive effects and potential resource occupation, Thompson et al. (2012) proposed a compromise view: when background music' s positive effects outweigh its negative effects, it facilitates cognitive processing; when negative effects outweigh positive effects, it hinders cognitive processing; and when positive and negative effects cancel each other out, no significant effect occurs. This "neutralization theory" attempts to separate and integrate two influences with different effect directions from the perspective of background music, providing a preliminary explanatory framework for the contradictory status quo of music effects. However, this model has not resolved the fundamental differences between the two pathways, particularly lacking systematic analysis of the mechanistic differences between advance and background music (see Figure 1 [Figure 1: see original paper]).

Figure 1 Similar state changes in individuals under different forms of music listening

1.3 Attention: The Core Hub Connecting Music and Cognition

Faced with these theoretical dilemmas, a potential breakthrough lies in re-examining the role that attention plays in music listening effects. We argue that attention is not merely an ordinary component among many cognitive functions but rather serves as a critical "cognitive hub" between music-induced psychological state changes and ultimate cognitive task performance (Fernandez et al., 2019; Lavie, 2005). Music' s impact on cognition is largely achieved by modulating the allocation state and efficiency of attentional resources.

First, music possesses unique advantages in regulating attention due to its universality and effectiveness in evoking emotional responses (Romand, 2015). Listening to music can elicit strong and stable emotional experiences, and emotional states are key variables that regulate attentional resource allocation (Fernandez et al., 2019). According to Fredrickson' s (2001) Broaden-and-Build Theory, positive emotions help broaden individuals' attentional scope, making them more inclined toward global processing (Rowe et al., 2007); conversely, negative emotions may narrow attentional scope, focusing more on local details or threat-related information (Jiang et al., 2011). The neural basis of this process is believed to involve functional coupling between the limbic system and prefrontal cortex (Ferreri et al., 2014, 2015; Pessoa, 2009).

Attention may also serve as a key node between background music's interference effects and cognitive impairment. When performing cognitive tasks, individuals need to concentrate limited attentional resources on task goals, while background music, as a task-irrelevant external input, triggers automatic processing responses that divert attentional resources (Perham & Vizard, 2011). This resource competition intensifies the regulatory pressure on the attention system between task-relevant and task-irrelevant stimuli, particularly when music content is complex or semantically related to the task (Perham & Currie, 2014; Salamé & Baddeley, 1989). If individuals' attentional control abilities cannot effectively suppress interference from background music, cognitive performance is likely to decline (Avila et al., 2012; Kämpfe et al., 2011).

The potential for music' s regulatory effects on cognition to operate through attentional functions also stems from its unique spatiotemporal dynamics (Sarasso et al., 2022). According to the Dynamic Attending Theory (DAT), music' s acoustic structure, such as rhythmic periodicity and harmonic tension gradients, can "capture" neural oscillations in the brain, creating optimal temporal windows for processing at beat peaks (Fitzroy & Sanders, 2015; Hurley et al., 2018). This neural-level "phase-locking" mechanism enables listeners' attention to form predictive mobilization for future stimuli under music' s guidance, thereby enhancing selective responses and processing efficiency.

In clinical practice, music's rhythmic characteristics have been used to intervene in attentional control disorders such as ADHD. In individuals with Attention Deficit Hyperactivity Disorder, music with rapidly changing rhythms can significantly enhance auditory network activity, effectively supporting sustained attention maintenance (Wu et al., 2024; Luo & Zhang, 2025). These studies collectively support a "music-attention" coupling mechanism of neural plasticity and provide important evidence for how long-term auditory experience shapes attentional functions.

2. An Attention Network Theory Model of Music Listening

In summary, whether through emotional arousal, resource competition, or rhythmic guidance, music' s multiple influence pathways ultimately converge on the modulation of the attention system. Therefore, the attention system is not only the core cognitive hub connecting music-induced state changes with cognitive functional performance but also the key to understanding and integrating existing theoretical divergences. Based on this understanding, this article attempts to construct a more refined integrative model from the perspective of attention network theory to systematically address previous controversies regarding music listening effects.

2.1 Core Connotations of Attention Network Theory

Given that attention plays a central hub role in music listening effects, adopting a more refined attentional theoretical model to analyze its underlying mechanisms becomes crucial. Unlike traditional theories that treat attention as a single function, the Attention Network Model proposed by Posner and Petersen

(1990) aims to decompose the complex attentional process into three functionally and neurally relatively independent yet cooperatively operating sub-networks, thereby more precisely describing how humans achieve perceptual selection, resource allocation, and cognitive control when facing complex information. These three sub-networks are: the alerting network, orienting network, and executive control network. Using the Attention Network Model as a theoretical foundation provides us with a multi-module, multi-level explanatory framework and a key theoretical leverage for deeply understanding how music influences cognitive processing.

The alerting network is primarily responsible for maintaining a state of arousal and alertness to prepare for upcoming stimuli. This network relies on coordinated activity in the brainstem, right prefrontal, and parietal regions, and is significantly modulated by the noradrenergic system (Fan et al., 2005). Its functions can be further subdivided into two types: phasic alertness, referring to instantaneous attentional enhancement to sudden stimuli; and vigilance, referring to the ability to maintain task focus over extended periods (Petersen & Posner, 2012).

The orienting network is responsible for shifting and focusing attention in space, enabling individuals to rapidly move attentional resources from one stimulus location to another more goal-relevant spatial region. This network is closely associated with brain regions including the right parietal cortex, superior parietal lobule, and superior frontal gyrus, and relies on cholinergic system neuromodulation (Posner, 1980).

The executive control network is the most advanced and complex subsystem in the model, primarily responsible for monitoring conflicting information, inhibiting irrelevant interference, and achieving flexible task switching when facing such conflicts. It is typically activated in tasks requiring cognitive conflict resolution (such as the Stroop task), with neural bases broadly involving the anterior cingulate cortex, dorsolateral prefrontal cortex, and related frontoparietal control pathways (Posner, 1992; Posner & Petersen, 1990).

With research progress, the Attention Network Model has gradually evolved into a systematic Attention Network Theory, which not only describes static functional distributions but also emphasizes dynamic interactions and upstream-downstream regulatory mechanisms among attentional subsystems (Petersen & Posner, 2012; Posner, 2016). Applying Attention Network Theory to music listening research enables us to systematically dissect music' s differential effects on different attention sub-networks, providing a key integrative framework for understanding the complex relationships between "music-attention-cognition."

Accordingly, this article proposes the Attention Network Model of Music Listening (see Figure 2 [Figure 2: see original paper]), with core assumptions including: (1) attention is the core hub through which music listening influences cognitive functions, with state changes such as emotional experience and cognitive load induced by listening serving as prerequisites for activating this pathway; (2)

different forms of music (advance vs. background) can respectively act upon different attention sub-networks (alerting, orienting, and executive control), with significant differences existing in the direction of their regulatory effects on executive control functions; and (3) moderating variables (such as temporal dynamics, optimal arousal level, and optimal load level) determine the direction and strength of music effects, providing explanatory pathways for understanding individual differences in effects.

Figure 2 Attention Network Model of Music Listening

2.2 Common Pathway of Music Listening' s Influence on Attention Networks: Pleasantness

Music can modulate attentional capacity in differentiated ways by inducing changes in state-based psychological resource allocation (Orpella et al., 2023). Whether advance or background music, their influence typically includes modulation of individuals' subjective pleasantness (Schäfer et al., 2013). According to the Broaden-and-Build Theory, different emotional experiences alter the distribution patterns of attentional resources and trigger changes in individuals' information processing strategies (Gasper, 2004; Huber et al., 2004). Therefore, different levels of pleasantness may play a regulatory role in the music-attention pathway, particularly within the orienting network (Posner & Petersen, 1990). In music listening contexts, features such as major mode, fast tempo, and harmonic structure are typically associated with higher subjective pleasantness. This can broaden individuals' attentional scope, enhance sensitivity to peripheral stimuli, and subsequently improve orienting speed and flexibility (Putkinen et al., 2017; Rowe et al., 2007). However, this broader attentional distribution may also have negative consequences, particularly impairing executive control abilities in tasks with high control demands due to attentional dispersion (Hu et al., 2017). A systematic review noted that compared to neutral stimuli, music with different emotional valences may indirectly affect task performance by expanding or narrowing the scope of executive control (Ahumada-Méndez et al., 2022).

In contrast, negative emotions typically manifest as attentional focusing effects. Musical features such as slow tempo, minor mode, or low pitch are often considered to induce low-pleasantness emotional states, thereby enhancing alerting levels (Jiang et al., 2011). This process may also improve processing efficiency for goal-relevant information. For example, Särkämö et al. (2014) found that sad music can enhance executive control performance to some extent, particularly in tasks requiring high attentional inhibition. This differentiated pathway challenges traditional linear explanations of emotional impact within the Mood-Arousal Hypothesis and provides a new theoretical perspective for understanding music' s cognitive effects. Simultaneously, it explains why happy or preferred music does not necessarily produce stable facilitative effects, and why "sad music" may also have positive effects in certain task categories.

Research has shown that listening to music inducing positive emotions improves individuals' detection speed and task performance in paradigms testing focused attention (Begum et al., 2019; Herlekar & Siddangoudra, 2019). In sustained attention response tasks, advance music listening improves the efficiency of vigilance maintenance compared to control groups without rest (Baldwin & Lewis, 2017). These two types of tasks can respectively map onto the phasic and sustained functions of the alerting network.

Furthermore, the rhythm-attention synchronization mechanism emphasized in the aforementioned Dynamic Attending Theory actually integrates features of both state-based and phasic alertness: Large and Jones (1999) proposed that attentional resources are "attracted" by external rhythms and reach peak activity at beat points (temporal attending peaks), meaning that in rhythmically clear music, humans predict the importance of upcoming time points and adjust attentional resources accordingly (Escoffier et al., 2010). Consequently, individuals exhibit fluctuating patterns of resource concentration and release during music listening that unfolds over time. This finding provides crucial clues for understanding the temporal mechanism by which background music affects alerting levels and particularly emphasizes the key role of acoustic parameters (Bolger et al., 2013, 2014).

Additionally, from a theoretical extension perspective, this "rhythm-attention synchronization" mechanism not only reflects the dynamic fluctuations of alertness states over time but can also be viewed as a temporal domain extension of "orienting function"—that is, individuals selectively focus attention on future time points through rhythmic prediction. This "temporal orienting" shows high functional similarity with spatial orienting in the traditional sense, providing a cross-dimensional supplementary perspective to the classic tripartite attention network model (Nobre & Van Ede, 2018).

2.3 Arousal Pathway: Non-Linear Modulation Based on "Optimal Arousal Level"

Modulating arousal level is one of the most direct pathways through which music listening influences the attention system, as the locus coeruleus-noradrenergic system, the primary neural basis of arousal, also plays a central role in the alerting network (Fan et al., 2005). Music' s tempo, volume, and structural complexity can effectively modulate individuals' physiological and psychological arousal levels: fast tempo, high intensity, and complex structures typically induce higher arousal levels, whereas slow tempo and soft tones often have arousal-reducing effects (Jiang et al., 2011; Schäfer et al., 2013). Therefore, music can significantly enhance alerting network function by modulating arousal levels, increasing sensitivity and response preparation to external stimuli.

However, music's effects on cognitive performance are not always positive, being modulated by a critical factor: individuals' "optimal arousal level." This concept originates from the classic Yerkes-Dodson Law, which posits an inverted

U-shaped relationship between arousal level and task performance (Yerkes & Dodson, 1908). Only when arousal is at a moderate level can cognitive efficiency be optimized. Therefore, when individuals are in low arousal states, moderate stimulation can improve performance; however, further arousal increases trigger stress and anxiety, 反而导致认知效率下降 (Nieuwenhuis, 2024).

Researchers have found that people spontaneously and actively use music listening to adjust their arousal levels to an optimal state matching task demands (Kiss & Linnell, 2022). For example, when performing relatively simple or skilled tasks, individuals tend to choose rhythmically strong music that helps push them into the optimal arousal range and improve performance; whereas when performing complex, difficult tasks, they prefer soothing background music or even silence. The concept of "optimal arousal level" can also explain why certain music types produce interference effects. One study comparing effects of music with different arousal levels found that high-arousal electronic dance music significantly impaired task performance, while structured, predictable classical music (such as Mozart' s K.448 sonata) showed positive facilitative effects in the short term (Sun, 2025). This may be because highly stimulating music exceeds individuals' processing capacity and task demands, pushing their arousal level into the hyperarousal range and thereby impairing cognitive function. Similarly, other studies have found that rock music significantly impairs sustained attention task performance compared to pop music (Thomson & Rakesh, 2024). Conversely, when individuals' arousal levels fall below the optimal range, music listening serves as an effective recovery strategy that can objectively improve reaction speed decreased by fatigue and other factors (Ding et al., 2025). Thus, optimal arousal level not only reveals music' s potential negative effects but also explains its complex role as a cognitive regulation tool: individuals' music listening behaviors and choices can help them maintain optimal arousal states across tasks with different cognitive demands.

Meanwhile, different attention sub-networks show differential dependence on arousal levels. As previously described, the alerting network is most sensitive to increases or decreases in arousal level. However, aside from the Mozart effect, few studies have found music's modulatory effects on other spatial orienting abilities (Aheadi et al., 2010). Relatively speaking, the executive control network is most sensitive to constraints of "optimal arousal level" because its operation highly depends on precise resource allocation: insufficient arousal leads to attentional dispersion and control laxity, while excessive arousal may cause strategic rigidity and executive conflicts (Li et al., 2023). Overall, arousal state effects on the attention system demonstrate high non-linear characteristics and task dependence.

The temporal dimension is a crucial yet often oversimplified factor in understanding music' s cognitive effects. This model proposes that music' s effects on attention have temporal dynamics, evolving in stages during listening. In the initial listening stage, music' s effects are dominated by the emotional-arousal pathway, with novel or pleasant music rapidly activating the brain' s reward system, releasing dopamine, and quickly inducing positive emotions and physiological arousal (Salimpoor et al., 2011). During this phase, motivational and emotional gains from music often facilitate task performance. However, as listening duration extends, music' s effects undergo critical transitions. For example, habituation phenomena cause individuals' responses to continuous stimuli to weaken, gradually diminishing music' s initial arousal and emotional enhancement effects (Kiss & Linnell, 2021).

This dynamic is particularly prominent in advance music research, as advance music' s effects particularly depend on the maintenance and extension of emotional aftereffects. Studies have noted that when the time interval between advance music and subsequent cognitive tasks is too long, its facilitative effects significantly weaken or even disappear completely (Thompson et al., 2001). This finding indicates that music-induced psychological states have temporal dynamics, with modulatory effects potentially decaying with delayed task onset. This suggests that temporal dynamic factors and arousal effect maintenance strategies need to be considered when designing music intervention or experimental protocols.

2.4 Cognitive Load Pathway: Specific Mechanisms of Background Music

Compared to advance music that operates through emotional or arousal modulation, background music, as a continuous external input, more easily enters into competitive relationships with core attention networks, thereby impairing executive control efficiency. This is because background music not only has psychological state-inducing functions but also, due to its unique dynamic acoustic properties, continuously occupies individuals' working memory and attentional resources, affecting cognitive performance (Jones & Macken, 1993), particularly when songs contain lyrics (Shih et al., 2012). Music's lyrics and high-complexity structures significantly increase cognitive load, while individuals' familiarity and preferences reduce subjective load (Nguyen & Grahn, 2017; Vasilev et al., 2018).

Among attentional subsystems, the executive control network is most sensitive to external cognitive load. Typical tasks such as working memory updating (n-back), inhibitory control (Stroop), and task switching heavily rely on frontal-prefrontal cortex resources, and background music processing also depends on these brain regions (Koelsch, 2011). Therefore, research indicates that background music may interfere with executive control functions. In contrast, advance music, which ends before task onset, does not continuously occupy cognitive resources and is more likely to facilitate cognitive processing through mechanisms such as emotional arousal, constituting an important mechanistic distinction between the two forms of music listening (Thomson & Rakesh, 2024). Similarly, when background music causes excessive load, it may weaken the sustained maintenance ability of alertness, reducing sensitivity to task initiation signals (Pessoa, 2009). Excessive cognitive load may also limit the flexibility of attentional orienting, making it difficult for individuals to switch attentional focus between music and tasks, impairing target localization efficiency (Pessoa, 2009).

However, cognitive load induced by background music does not always produce negative effects. Researchers have found that moderate external load may actually produce facilitative effects (Armitage et al., 2024). To explain this phenomenon, this article combines insights from Cognitive Load Theory and the Yerkes-Dodson Law to propose the moderating factor of "optimal load level" : background music' s impact on cognitive processing shows an inverted U-shaped non-linear relationship, meaning cognitive performance is optimal when the total cognitive load it induces approaches individuals' optimal range (Kämpfe et al., 2011). When external load is too high, it competes with the primary task for limited working memory resources, causing resource conflict and performance decline; when cognitive load is too low, individuals' remaining cognitive resources are more likely to cause task-unrelated internal distraction, namely mind-wandering, which also impairs task performance (Kiss & Linnell, 2021).

Further research shows that this optimal load effect is not fixed but is modulated by multiple factors. Regarding tasks, simple tasks are more likely to benefit from moderate listening, whereas complex tasks are more susceptible to music interference (Kiss & Linnell, 2022). Regarding individuals, working memory capacity and personality traits jointly determine load thresholds: extraverts and individuals with high working memory capacity better tolerate additional stimulation from music (Avila et al., 2012; Cassidy & MacDonald, 2007; Deng & Wu, 2020). Thus, the concept of "optimal load level" provides an explanation complementary to "optimal arousal level," emphasizing the individual differences and context dependence of music effects.

Interestingly, in background music contexts, phenomena such as decreased alertness due to extended listening duration also occur (Pietschnig et al., 2010). Therefore, temporal dynamics of music listening are also reflected in the cognitive pathway of background music. This is because continuous processing of background music constantly consumes limited cognitive resources, generating mental fatigue and subsequently causing attention decline and executive function impairment (Guo et al., 2015). When positive effects disappear due to habituation while negative cognitive load costs continuously accumulate, music listening effects may shift from facilitation to interference. Thus, we can distinguish and describe three stages affecting the temporal dynamics of music listening effects: short-term gains driven by arousal in the initial stage, transition to habituation adaptation in the middle stage, and finally potential performance decline due to cognitive load accumulation and fatigue during long-term exposure (Kiss & Linnell, 2021; Salimpoor et al., 2011).

In summary, the cognitive load pathway reveals the key mechanism by which background music acts as a cognitive distractor and emphasizes that its impact is not unidirectional or negative but rather context-dependent under specific task demands and individual conditions. Understanding this mechanism helps clarify the heterogeneity of background music effects across populations and provides a theoretical foundation for introducing multi-pathway regulatory mechanisms into the model. Incorporating "temporal dynamics" as a moderating factor enables us to simultaneously understand and explain the "time-sensitive" nature of advance music and the "diachronic" changes of background music. It suggests that the optimal strategy for advance music listening may be to cleverly "capture" benefits from the first stage before effects decay, while long-term background music listening means effects will inevitably transition from initial potential gains to later performance impairment. Only by fully understanding the temporal dynamics of listening can we truly master the double-edged sword of music.

3. Functional Generalization and Model Advantages: Contributions of Attention Network Theory

Attention Network Theory provides a novel integrative framework for exploring music' s cognitive effects. Its core advantage lies in its ability to parse music' s impact on basic attentional processing into differential modulation of distinct sub-networks—alerting, orienting, and executive control—thereby offering possibilities for explaining its broader, higher-order cognitive effects. This cross-level influence from basic attentional regulation to higher cognitive functions, termed "functional generalization," refers to the process by which external stimuli affect higher-order cognitive functions such as working memory, reasoning ability, and creativity by altering the state of the attention system (Gazzaley & Nobre, 2012; Petersen & Posner, 2012). Therefore, deeply investigating functional generalization of music' s influence within the framework of Attention Network Theory constitutes not only a key link to comprehensively understanding the mechanisms of music listening effects but also marks the expansion and construction of this theory from local effects to systematic models.

3.1 Functional Generalization from Attention Networks to Higher Cognition

At the theoretical level, researchers widely recognize the attention system as the core hub of the entire cognitive architecture, forming a solid foundation for functional generalization. Petersen and Posner (2012) note that attention networks are not isolated functional modules but rather, through their coordinative functions, are deeply involved in information integration and transmission between multiple neural networks, supporting full-process regulation from perceptual input to advanced task goal achievement. Numerous models of higher cognitive functions explicitly indicate their fundamental dependence on attentional resources. Whether Miyake et al.' s (2000) three-factor model of executive functions or Cowan' s (2001) working memory theory emphasizes that core functions such as inhibition, updating, switching, and focusing are essentially fine-tuned regulation of attentional resources. Therefore, any external input that can effectively optimize attention network efficiency—such as music—possesses the potential to influence higher-order cognitive processing by activating and modulating attention networks (Gazzaley & Nobre, 2012).

At the neural mechanism level, the "top-down modulation" model provides direct theoretical foundation for functional generalization. This model suggests that the cognitive control network is not only the common neural basis for selective attention and working memory but also a domain-general control center (Gazzaley & Nobre, 2012). More efficient executive control can enhance neural representations of task-relevant information, suppress interference from irrelevant information, and flexibly coordinate information flow between different brain regions (Dixon et al., 2018). Therefore, music listening' s impact on the executive control network is not limited to attention tasks but includes more effective management and mobilization of other cognitive resources (Hodges & Limb, 2025), such as enhanced working memory capacity or increased creative thinking (Xiao et al., 2023). fNIRS studies have found that while music enhances cognitive performance, it simultaneously reduces activity levels in the dorsolateral prefrontal cortex (Ferreri et al., 2013). This reveals that music listening does not simply increase individual motivation but rather reduces cognitive resource consumption for tasks by improving neural processing efficiency. Functional Magnetic Resonance Imaging (fMRI) studies confirm that music listening can simultaneously activate multiple large-scale brain networks, including ventral and dorsal attention networks, frontoparietal control networks, and default mode networks, indicating that music can broadly influence the brain' s functional integration state (Chan & Han, 2022). More specifically, music listening can enhance functional connectivity between the auditory network and the dorsolateral prefrontal cortex as an executive control hub (Heine et al., 2015), providing direct anatomical-functional pathway evidence for the functional generalization hypothesis.

Cross-frequency neural oscillation synchronization studies also provide evidence for cross-level modulation of the attention system (Canolty & Knight, 2010). Neural oscillations, as fundamental rhythmic neural activities underlying brain function, have different frequency bands associated with different cognitive states and computational processes. For example, modulation of alpha-band activity is closely related to attentional inhibition and release processes and serves as a neural marker for working memory and executive function activities (Klimesch, 2012). The brain achieves dynamic information processing through interactions between different rhythms and is particularly sensitive to external rhythmic inputs. Therefore, music can be considered an extremely effective neural entrainment tool (Ding et al., 2025). When people listen to music, neuronal clusters in auditory cortex and even broader motor and cognitive networks begin to fire rhythmically in time with the music' s beat (Ross & Balasubramaniam, 2022). Under passive listening conditions, when rhythmic stimuli are task-relevant, sustained low-frequency delta-band neural entrainment becomes robust (Bouwer, 2022; Doelling & Poeppel, 2015). Additionally, emotional experiences brought by music listening have also been found to induce specific changes in EEG rhythms, thereby enhancing the attention system' s selective processing capacity for external inputs (Sarasso et al., 2022). For instance, music's arousal level correlates with alpha wave suppression in the brain, while emotional valence or pleasantness correlates with enhanced theta waves in frontal regions (Rogenmoser et al., 2016). Therefore, music can promote neural coupling between perceptual input and cognitive control systems by guiding phase synchronization across multiple frequency bands (Baldwin & Lewis, 2017).

Furthermore, music training, as a highly structured and long-term musical experience, can provide indirect evidence for the "functional generalization" mechanism through its reflection of individual cognitive changes in attention regulation and cognitive function transfer (Zhao, 2024). Extensive cross-population studies consistently show that individuals with long-term musical training exhibit significant cognitive advantages in multiple non-musical domains including executive control, working memory, cognitive flexibility, and language ability (Bialystok & DePape, 2009; Putkinen et al., 2015; Zuk et al., 2014). Critically, a meta-analysis demonstrates a clear dose-response relationship, providing mechanistic insights into how music training translates into cognitive gains. For example, significant improvements in preschool children' s inhibitory control (SMD = 0.38, 95% CI: 0.16–0.6) are closely related to music training duration ($ 12*weeks*), *frequency*($3 times per week), and single-session length (20–30 minutes); their working memory capacity (SMD = 0.35, 95% CI: 0.16–0.54) and cognitive flexibility (SMD = 0.23, 95% CI: 0.04–0.42) are also significantly enhanced with music training duration and frequency. This dose-dependency transcends simple correlation and strengthens causal inference.

These broad cognitive advantages are often accompanied by profound neurostructural and functional reshaping of attention regulation systems (Chen et al., 2020; Doelling & Poeppel, 2015), particularly in key brain regions such as the prefrontal cortex and parietal networks (Hyde et al., 2009; Strait & Kraus, 2011b). Music training also specifically reshapes interactions between large-scale brain networks. Longitudinal studies have found that instrumental training can increase resting-state functional connectivity within sensorimotor networks and between auditory and motor regions (Cantou et al., 2018). Research on improvising musicians shows optimized connectivity between their executive control network and default mode network, reflecting enhanced attentional inhibitory control (Ma et al., 2024). Meta-analyses reveal that compared to novices, professional musicians show stronger activation in key nodes of the executive control network (such as the precentral gyrus and inferior frontal gyrus) (Wu et al., 2020). This robust phenomenon of neural plasticity and cognitive functional generalization provides important theoretical reference and model inspiration for understanding the broad impact and cross-level transfer pathways of immediate music listening effects (Zanto et al., 2022).

Increasing empirical studies support the "functional generalization" pathway through which music listening effects transfer to more complex cognitive processing via attentional modulation. Research has found that music listening can improve working memory performance, an effect particularly pronounced in tasks requiring high attentional control (Schellenberg et al., 2007). Researchers propose that structurally clear, emotionally positive music can improve information encoding and maintenance processes by optimizing attentional resource allocation. Other studies have found that even short-term music interventions lasting only 20 days significantly improve children’ s executive control and language abilities (Moreno et al., 2011).

3.2 Integrative Advantages of Attention Network Theory

The double-edged sword effect of music listening suggests that music’ s impact on different cognitive processes may differ, but the source of these differences remains an unresolved core question. Traditional Mood-Arousal Hypothesis and Limited Capacity Theory are often viewed as isolated or even opposing perspectives, whereas this model treats them as different regulatory pathways acting upon attention networks (pleasantness, arousal, and cognitive load pathways) and posits that their combined effects determine ultimate cognitive outcomes. Adopting the perspective of Attention Network Theory to reconstruct the explanatory framework for music listening effects successfully integrates them under a more inclusive dynamic regulatory framework, helping bridge divergences among various theoretical hypotheses.

Second, this model greatly enhances explanatory precision and systematicity. This theory makes the first attempt to clarify similarities and differences in pathways through which two different listening forms—background and advance music—influence cognitive functions, and innovatively introduces temporal dynamics as a moderating variable, contributing to a more comprehensive understanding of the complex effects of music listening. In specific model construction, by decomposing the general concept of “attention”into three functionally distinct sub-networks—alerting, orienting, and executive control—we can more precisely analyze which attention network specific music types or listening forms affect, thereby explaining why music has vastly different impacts on different cognitive tasks. We also introduce factors with individual variability such as optimal arousal level and optimal load level to more comprehensively understand the complex influences of music listening effects.

This theory constructs a relational framework based on the mutual matching among musical features, temporal parameters, and individual variation, breaking through the traditional binary “facilitation-interference” categorization limitation and providing scientific, detailed explanations for understanding the high context-dependence and individual differences in music effects.

Finally, this model also demonstrates promising application prospects at the practical level, providing important theoretical anchors for clinical intervention, educational optimization, and commercial human-computer interaction. For example, in workplace settings, this model can guide how to achieve more efficient work performance through background music. For sustained tasks requiring long-term focus and high repetitiveness, timely background music can help employees maintain stable emotional states and high task focus; for intermittently performed high-intensity cognitive activities, specific types of advance music can be arranged beforehand to 发挥 its priming role in the pre-task phase. Additionally, in educational contexts, this theory shows great potential. Teachers can select appropriate music listening forms as auxiliary tools based on characteristics of students' current learning content to promote knowledge absorption or memory processes, or to enhance individuals' creativity (Ritter & Ferguson, 2017). Moreover, the inclusion of temporal parameters can provide optimization pathways for neuroergonomics—for example, dynamically switching between background/advance music modes by real-time EEG monitoring of alpha-band power to achieve personalized cognitive enhancement.

4. Unaddressed Issues and Research Prospects

Based on the Attention Network Model, this review proposes that music listening may broadly influence higher cognitive functions by modulating different sub-networks of the attention system. This model emphasizes that attention is not only a basic input mechanism for cognitive processing but also the core hub through which music-induced individual state changes are transmitted to cognitive performance (Mendes et al., 2021). However, more empirical research is needed to test the theoretical propositions proposed in this article and to generate exploratory discoveries.

4.1 Testing Model Robustness of Attention Network Theory

Current empirical research has not systematically verified the hypothesis that music listening produces differential effects on different attention sub-networks; its model robustness and theoretical explanatory power remain to be further empirically supported. First, more research should directly test music' s modulatory effects on attention sub-networks. For example, using task paradigms highly matched to the three major attention sub-networks, such as the Attention Network Test (Fan et al., 2002), combined with fMRI technology to measure activation changes in brain regions related to alerting, orienting, and executive control during music listening. By comparing modulation amplitude and direction of different emotional and complexity music stimuli in each attention sub-network, specific regulatory pathways can be clarified (Fernandez et al., 2019; Jiang et al., 2011). To overcome causal limitations of correlational evidence, transcranial magnetic stimulation (TMS) technology can also be used to selectively inhibit specific attention sub-networks and observe whether music listening effects disappear; or combined with neurofeedback training paradigms to guide participants to actively regulate prefrontal activation levels, testing the necessity and sufficiency of the executive control network in music effects.

Second, the generalization process through which music regulates higher cognitive functions based on attention networks should be further tested for stable existence. For example, using cross-task designs to compare performance differences of music modulation across different task types can determine whether its regulation is task-specific. Future research explaining music' s impact on higher cognition (such as creativity, reasoning) can incorporate changes in attention network efficiency as potential mediating variables into measurement and analysis. Methods such as structural equation modeling and path analysis can be used to test whether attention networks play a mediating role between "music-cognition." These strategies not only help verify model assumptions at the neural mechanism level but also help expand the application boundaries of Attention Network Theory.

4.2 Comparing Commonalities and Differences Between Two Listening Forms

Although this study systematically reveals the heterogeneity of background and advance music in cognitive regulatory pathways, experimental studies directly comparing the two listening forms remain significantly lacking in current literature. Notably, research on advance music has shown a clear downward trend after early explosive growth, forming a sharp contrast with the continued prosperity of background music research. This imbalance may stem from methodological challenges: the time-decay characteristic of advance music effects requires experimental designs to precisely control inter-task intervals, for example, shorter than 15 minutes (Thompson et al., 2001), yet previous studies have not established standardized experimental paradigms. Investigating the commonalities and differences between the two listening forms is a method to improve the ecological validity of music listening effects. Future research should focus equally on advance music listening effects while continuing to study background music. This will not only benefit the complete construction of this theory but also enhance the practical and application value of music listening in work and learning contexts.

4.3 Testing and Exploring Moderating Factors

Future research on music listening effects should further control or examine the contributions of moderating factors proposed in this article to clarify the complex interactions between music listening and attention networks. Particularly noteworthy are the testing of concepts such as "optimal arousal level" and "optimal cognitive load level." For example, acoustic structural complexity may affect task performance by generating cognitive load, but research has found that not all acoustic changes produce additional harmful effects (Schweppe & Knigge, 2020).

Methodologically, computational modeling approaches can be combined to simulate dynamic competition processes between musical attributes and task resources, providing concrete support for quantitative modeling of complex cognitive regulatory mechanisms. For example, reinforcement learning frameworks can be adopted to operationally define key state variables such as music complexity and task demand levels, enabling simulation of dynamic interactions between acoustic attributes and cognitive demands.

At the individual level, factors such as gender and personality type may influence music listening effects; while musical training background and reward sensitivity differences may also cause heterogeneity in listening effects—for example, musically trained individuals show greater ease in processing parallel resource allocation between music and tasks (Strait & Kraus, 2011a). Future research can use mixed-effects models to quantify hierarchical moderating contributions of individual variables on the "music-attention-cognition" pathway, parsing specific pathways and strengths of these moderating effects to provide more solid empirical support for the practical application of this theory.

From the academic debate sparked by the early "Mozart effect" to recent explorations of music-cognition interaction neural mechanisms, music listening effects have attracted increasing attention and research. Empirical evidence indicates that the specific direction of music listening's cognitive effects is complex and dynamically modulated by multiple factors including musical features, task types, and individual differences. This article reviews representative research on music listening effects and further explores the critical role of attentional functions as a cognitive hub in the process of music influencing cognitive processing. This article attempts to examine the internal mechanisms through which music listening exerts cognitive effects from the perspective of the Attention Network Model. First, we comparatively analyze potential differences between advance and background music in state-regulating pathways such as emotional experience and cognitive resource occupation, then propose that attention networks may serve as important cognitive hubs mediating between music-induced state changes and cognitive performance changes. Finally, based on relevant research evidence, we propose hypotheses about potential moderating factors and suggest possible future research directions. The introduction of Attention Network Theory provides a structured model for understanding the potential cognitive mechanisms of music listening effects, refines the possible influences on different classifications and levels of cognitive functions, and offers a more convincing explanatory framework for previously relatively isolated empirical results.

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Note: Figure translations are in progress. See original paper for figures.