# Does Listening to Classical Music Really Make You Smarter? A Postprint of a Meta-Analysis of the Generalized Mozart Effect

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## Abstract

Does the Mozart effect exist? If so, what is its underlying mechanism? These questions remain unresolved and are currently subject to intense debate. To clarify the facilitative effects of classical music on cognitive performance and their influencing factors, and to elucidate the mechanism underlying the Mozart effect, this study conducted a meta-analysis using a random-effects model on 91 retrieved studies (172 independent effect sizes, 7,159 participants). The results revealed that, after excluding outliers, classical music significantly improved cognitive performance, with a small overall effect size (Hedges' g = 0.36, $p < 0.001$). The relationship between the two was moderated by age, cultural background, type of experimental design, and the dominant hemisphere of the brain corresponding to the task, and there were interaction effects between gender and age, cultural background, and dominant hemisphere. Furthermore, the direct priming hypothesis received stronger support, but the mechanism underlying the Mozart effect still requires further investigation. Future research should further clarify the mechanism underlying the Mozart effect and other potential moderating variables, thereby helping people to view the effects of Mozart' s music more rationally and comprehensively, and to conduct music education more appropriately.

## Full Text

## Preamble

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· Meta-Analysis ·

**Does Listening to Classical Music Really Make You Smarter? A**

# Meta-Analysis Based on the Generalized Mozart Effect

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**Abstract**
Does the Mozart effect exist? If so, what is its underlying mechanism? These questions remain unresolved and hotly debated. To clarify the facilitative effects of classical music on cognitive performance and their influencing factors, and to explore the mechanism of the Mozart effect, this study conducted a meta-analysis of 91 retrieved studies (172 independent effect sizes, 7,159 participants) using a random-effects model. After excluding outliers, results showed that classical music significantly improved cognitive performance with a small overall effect size (Hedges' $g = 0.36$, $p < 0.001$). This relationship was moderated by age, cultural background, experimental design type, and the dominant hemisphere corresponding to the task, with significant interactions between gender and age, cultural background, and dominant hemisphere. Furthermore, the direct priming hypothesis received stronger support, though the mechanism underlying the Mozart effect requires further investigation. Future research should further clarify the mechanism and other potential moderating variables to help people view the effects of Mozart' s music more rationally and comprehensively, and to inform music education practices.

**Keywords:** Mozart effect; classical music; meta-analysis; music cognition
**Classification Number:** B848

Can listening to classical music make people smarter? This enduring question reflects sustained public interest in the relationship between music and cognitive performance. In 1993, Rauscher et al. discovered that listening to 10 minutes of Mozart' s "Sonata for Two Pianos in D Major" (K.448) improved participants' performance on spatial reasoning tasks, a phenomenon they termed the "Mozart Effect" (Rauscher et al., 1993). This finding subsequently attracted widespread attention from both academia and the business community (Campbell, 2000; Waterhouse, 2006). Researchers later found that listening to other Mozart compositions could also enhance spatial reasoning performance (Lange-Küttner & Rohloff, 2020; Lints & Gadbois, 2003), and that other classical music could promote cognitive performance as well (Foster & Valentine, 2001; Nantais & Schellenberg, 1999), leading to phenomena such as the "Vivaldi Effect" (Mammarella et al., 2007). Consequently, definitions of the Mozart effect can be narrow or broad. The narrow definition refers to the phenomenon where listening to a specific type of music (generally Mozart' s) temporarily improves spatial reasoning ability (Wu et al., 2014). According to psychology' s definition of cognition as the mental process of knowing and understanding, involving knowledge acquisition, use, and manipulation—including perception, attention, imagery, learning, memory, thinking, and language (Lin et al., 2003)—the broad Mozart effect can be summarized as classical music promoting individuals' cognitive performance, such as improving scores on cognitive tasks including spatial reasoning, reading comprehension, and mathematics tests (Aoun et al., 2005; Jones & Zigler, 2002). Classical music generally refers to music composed within mainstream European cultural contexts, extending from the Renaissance period to the late 19th and early 20th centuries, distinguished from popular music by its complex and diverse compositional techniques and profound expressive capacity (Sun, 2011).

However, some studies have failed to find the Mozart effect (Giannouli et al., 2019; Standing et al., 2008; Steele et al., 1997), sparking controversy and skepticism focused on three questions: Does the Mozart effect exist? How is it generated? What factors influence it? Faced with these controversies, drawing conclusions based on simple individual or small-scale experimental reports is neither scientific nor cautious. Although three previous meta-analyses have evaluated the Mozart effect (Chabris, 1999; Hetland, 2000; Pietschnig et al., 2010), all were based on the narrow definition, focusing on "whether listening to Mozart improves spatial reasoning ability." They could not adequately answer the highly popular question "Can listening to classical music make people smarter?" nor address the above controversies. Therefore, this study expands the scope and number of studies included in the meta-analysis, encompassing more diverse classical music and cognitive tasks across broader and multi-context samples to re-examine this topic. Moreover, for the first time, we compare the two competing theoretical explanations—direct priming hypothesis and indirect arousal-mood hypothesis—to elucidate the underlying mechanism. Additionally, we examine potential reasons for divergent findings from multiple perspectives, including participant characteristics (gender, age group, cultural background), experimental task and design features (music presentation order, experimental design type, control group type, cognitive task type and its dominant hemisphere), and interactions among key variables, which holds significant implications for future child cognitive development and music education (see Figure 1 [Figure 1: see original paper]).

### 1.1 Reliability of the Mozart Effect

Evidence supporting and opposing the Mozart effect is roughly equivalent. Behavioral experiments show that listening to Mozart indeed improves performance on spatiotemporal reasoning tests (Aheadi et al., 2010; Padulo et al., 2020; Rauscher et al., 1993; Smith et al., 2010). Meanwhile, cognitive neuroscience evidence supports that Mozart' s music uniquely affects specific brain activities (Jausovec & Habe, 2004; Rideout & Laubach, 1996; Verrusio et al., 2015; Zhu et al., 2008), such as reducing EEG activity and improving cognitive performance (Jausovec et al., 2006), enhancing alpha rhythm activity in healthy elderly and children (Mualem et al., 2021), and altering P3a and P3b amplitude and latency (Zhu et al., 2008). However, many studies have failed to find Mozart's facilitative effect on spatiotemporal reasoning (Borella et al., 2017; Crncec et al., 2006; Steele, Bass et al., 1999), thus questioning the reliability of the Mozart effect (Steele, Bella et al., 1999).

The three previous meta-analyses showed large differences in overall effect sizes and inconsistent conclusions about the existence of the Mozart effect. Chabris (1999) found no facilitative effect of Mozart music on integrated spatial and abstract reasoning tasks (d = 0.09), but this study had a small sample size and did not test for publication bias, potentially leading to biased results. Hetland (2000) included 36 studies, including unpublished research, covering broader music types and control conditions, reporting an overall effect size of 0.46. Pietschnig et al. (2010) included 39 studies, categorizing Mozart K.448 separately (Category 1) and other music stimuli (including other Mozart pieces, other classical music, pop music, etc.) as Category 2, obtaining effect sizes of 0.37 and 0.38 respectively for music versus non-music controls on spatial reasoning tasks. These meta-analyses had ambiguous definitions of the Mozart effect, 不规范 classification and definition of music types (e.g., experimental groups included light music and pop music in addition to classical music), making it difficult to clarify the relationship between listening to classical music and individual cognitive performance. Second, they inadequately explored potential moderating factors: none examined variables such as cultural background or music presentation order, let alone interactions among potential moderators. Moreover, all samples came from Western cultural backgrounds, lacking attention to Chinese samples, which is insufficient for adjudicating the reliability of the "Mozart effect."

### 1.2 Mechanism of the Mozart Effect

Two main theories compete to explain the Mozart effect' s mechanism: "direct priming hypothesis" and indirect "arousal-mood hypothesis." Inspired by Leng et al.' s Trion model (Leng et al., 1990), Rauscher' s direct priming hypothesis posits that the Mozart effect arises from direct priming effects—listening to Mozart K.448 and performing spatial tasks share similar neural firing patterns in the cortex, so music processing directly primes brain regions involved in spatial tasks, thereby enhancing spatial ability (Rauscher, Robinson et al., 1998). Thus, direct priming focuses on explaining the narrow Mozart effect. This hypothesis has received partial support from behavioral and cognitive neuroscience studies (Bodner et al., 2001; Bolander & Callahan, 2021; Eskine et al., 2020; Gultepe & Coskun, 2016; Sarnthein et al., 1997; Suda et al., 2008). In contrast, the arousal-mood hypothesis suggests that listening to music changes participants' mood and arousal level, indirectly improving various cognitive performances (Thompson et al., 2001). Research shows cognitive enhancement occurs because Mozart music increases arousal levels (Borella et al., 2014; Lints & Gadbois, 2003), and the Mozart advantage disappears after controlling for arousal (Thompson et al., 2001). Additionally, listening to pleasant music promotes dopamine release (Nadler et al., 2010), thereby facilitating cognitive performance and strengthening learning (Gold et al., 2013). A recent study found both Mozart K.448 and self-selected music enhanced cognitive performance by increasing participants' pleasure, indirectly affecting cognition but independent of Mozart music' s specific characteristics (Gavazzi et al., 2021). In summary, both direct priming and arousal-mood hypotheses have received empirical support, but no meta-analysis has compared them, leaving the mechanism unresolved. This study compares these two theories to elucidate the underlying mechanism.

### 1.3 Potential Moderating Variables: Participant Characteristics

**1.3.1 Gender** Gender may influence the relationship between classical music and cognitive performance. First, initial Mozart effect research focused on spatial cognition, which shows gender differences (Caplan et al., 1985; Voyer et al., 1995). This advantage appears even in infancy (Moore & Johnson, 2008; Quinn & Liben, 2008) and may relate to gray and white matter differences: women have higher gray matter density, while men have higher white matter density per unit volume (Ruigrok et al., 2014). Gray matter primarily relates to stimulus and information processing, giving women potential advantages in language and emotional processing, while white matter mainly transmits commands, potentially giving men advantages in spatial cognition (Lauer et al., 2019). Additionally, women reportedly prefer classical music more than men (Aljanaki et al., 2016), show greater willingness to understand classical music, engage in active imagination, and derive higher aesthetic experiences from it (Jiang & Zhu, 2011). Therefore, we hypothesize classical music' s effects may be closely related to gender, though this factor has been underemphasized in previous research with inconsistent conclusions. Pietschnig et al. (2010) did not analyze gender differences; Gilleta et al. (2003) found classical music facilitated women' s mental rotation performance but not men' s; Wu et al. (2014) found Mozart music significantly improved girls' spatiotemporal reasoning but not boys' ; Hallam et al. (2002) found opposite results with no gender differences in memory tasks; Hetland (2000) examined gender differences in spatial cognition tasks but found non-significant results based on gender ratios in included studies, a classification method that may lack precision. To further explore this issue, this study will systematically analyze independent data for males and females across included studies.

**1.3.3 Cultural Background** The relationship between classical music and cognitive performance may also be influenced by cultural background. Cultural factors play important roles in music emotion perception and other cognitive processes (Arikan et al., 1999; Hu & Lee, 2016). Early Mozart effect research primarily used Western cultural backgrounds and participants, though domestic research has grown (Huang, 2009). However, music cognition results from one cultural context may differ from others (Chen et al., 2011). Empirical studies confirm that attention resource allocation (Arikan et al., 1999), scale structure perception (Neuhaus, 2003), and EEG changes in musicians relate to cultural background (Nan et al., 2006), while cultural factors affect overall music cognitive strategies (Neuhaus, 2003). Western classical music, represented by Mozart, is highly artistic and logically rigorous, emphasizing emotional expression with wide ranges, varied melodies, robust tunes, and grand structures, focusing on rhythm and momentum. In contrast, Chinese folk music emphasizes artistic conception and harmony between humans and nature, advocating subtlety, harmony, beauty, and depth (Sun, 2011), showing huge differences in content, style, aesthetics, and music education philosophy (Zhang, 2012). When music stimuli and participants share the same culture, participants more easily understand musical emotions (Heng, 2018), which may enhance arousal, improve attention, and produce greater positive effects on cognitive performance (di Muro & Murray, 2012; Zhu et al., 2009). Chinese participants are primarily influenced by Chinese folk music, potentially differing from other cultural groups in understanding classical music. Therefore, this study posits that Mozart music may have different effects on listeners from different cultural backgrounds.

### 1.4 Potential Moderating Variables: Design Features

**1.4.1 Music Presentation Order** Music presentation order may also affect the classical music-cognition relationship. According to seductive detail effect theory (Rey, 2012) and cognitive load theory (Paas et al., 2003), background music causes learners to allocate some cognitive resources to processing music, increasing cognitive load, distracting attention, and causing interference that impairs task performance (Ferreri & Verga, 2016; Nemati et al., 2019; Rey, 2012; Shek & Schubert, 2009; Wang et al., 2020), particularly for tasks requiring high concentration like reading comprehension (Kaempfe et al., 2011). Pre-task music is less likely to interfere with cognitive tasks and may induce positive emotions (Storbeck & Clore, 2005). EEG studies show P3 amplitude increases most significantly with pre-task music, yielding the best cognitive facilitation (Sun et al., 2013); pre-task music helps reading performance while background music interferes (Chen & Dong, 2008). However, some studies suggest pre-task music is less effective than background music (Silva et al., 2020). Therefore, this study further examines whether differences exist between pre-task and background music effects on cognition.

**1.4.2 Experimental Design Type** Rauscher et al. (1998) suggested that failure to replicate the Mozart effect may relate closely to experimental design type. In within-subjects designs, each participant undergoes repeated measurements of the dependent variable, potentially causing "carryover effects" that mask the Mozart effect (Charness et al., 2012). Specifically, pre-test tasks or cognitive tasks following music conditions may activate relevant brain regions that persist into subsequent control conditions (e.g., silence), improving performance in control conditions and reducing differences between experimental and control conditions. Between-subjects designs yield larger differences because each participant experiences only one condition, avoiding cross-condition interference (Thompson & Campbell, 2004), and control groups' brains are not pre-activated, preventing masking of music's enhancement effects. Indeed, studies controlling for carryover effects show larger effect sizes than those without such controls (Hetland, 2000). Therefore, this study hypothesizes that experimental design type moderates the Mozart effect, with between-subjects designs producing larger effect sizes than within-subjects designs.

**1.4.3 Control Group Type** Whether classical music promotes cognitive performance may directly relate to the type of control music, as brain involvement differs across music types (Kaempfe et al., 2011). For example, EEG differences between classical and rock music concentrate in frontal and partial occipital lobes, while differences from silence concentrate in temporal lobes (Li et al., 2019). Comparing classical music to silence has yielded mixed results: some found classical music improved attention and memory (Li, 2009), while others suggested it distracted attention and interfered with cognitive activities (Li et al., 2019). Previous meta-analyses show inconsistent results: Chambris (1999) found no spatial cognition improvement after Mozart (d = 0.09), denying the Mozart effect; Pietschnig et al. (2010) found a combined effect size of d = 0.48 for Mozart versus silence, affirming Mozart’ s spatial cognition benefits. Thus, the effect size from classical music versus silence cannot determine whether classical music distracts or enhances attention. Synthesizing more individual study results (e.g., classical music versus silence) helps understand the overall trend. Furthermore, control music type importantly contributes to effect size heterogeneity. Compared to rock music, participants listening to Mozart showed no better word memory (Wang et al., 2020). However, compared to Chinese folk music, Mozart listeners showed significantly higher memory accuracy for unfamiliar complex words, higher emotional arousal, increased attention levels, and elevated heart rate (Li, 2009). Compared to pop songs, high school students showed better word memorization with classical music (Li, 2008). Thus, classical music’ s impact depends closely on whether and what type of music the control group hears. This study categorizes control groups into silence, non-music, pop music, and Chinese folk music groups.

**1.4.4 Dominant Hemisphere of Cognitive Tasks** Classical music’ s effects may vary by task characteristics and type. Some research suggests music’ s cognitive effects change with task nature (Proverbio & de Benedetto, 2018), facilitating spatial tasks (Jausovec & Habe, 2005) but having minimal effect on language tasks (Mullikin & Henk, 1985) or even causing distraction in reading comprehension (Dobbs et al., 2011; Vasilev et al., 2018; Zhang et al., 2018). A recent study found background music significantly improved working memory but not attention (Taheri et al., 2022). Similarly, attention tasks perform best in silence, calculation tasks best with classical music, and memory tasks similarly across music conditions (Hayashi, 2021). Thus, music’ s effects differ by task type, possibly related to cerebral functional lateralization. According to cerebral functional lateralization theory (Karolis et al., 2019), the left hemisphere dominates language and mathematics (Dehaene et al., 2003; Minagawa-Kawai et al., 2011; Price, 2010), while the right hemisphere dominates spatial tasks, music, and emotion (Gainotti, 2019). The hemispheric-activation hypothesis (Aheadi et al., 2010) suggests Mozart music improves spatial ability and visuospatial attention because both are right-hemisphere functions, and the right hemisphere primarily processes music (Bever & Chiarello, 1974; Desrocher et al., 1995; Santosa et al., 2014; Wang & Agius, 2018). Therefore, listening to music activates the right hemisphere and improves cognitive performance (Aheadi et al., 2010). This study further categorizes cognitive tasks by hemisphere, grouping language- and mathematics-related tasks in the left hemisphere and spatial tasks in the right hemisphere, comparing effect sizes between hemispheres and hypothesizing that classical music better facilitates right-hemisphere tasks.

### 1.5 Potential Interactions

**1.5.1 Gender × Age Group** Classical music' s cognitive effects may be influenced by the interaction between gender and age. First, gender differences in cognitive development vary by age. Research shows male advantages in spatial ability increase with age (Neuburger et al., 2011; Palejwala & Fine, 2015), while gender differences in verbal ability also vary by age (Hyde & Linn, 1988). Adolescence is considered a sensitive period for hormone secretion, with gender differences in endocrine levels affecting cognitive gender differences (Berenbaum & Beltz, 2011; Herlitz et al., 2013). Additionally, music emotion perception is influenced by age-gender interactions (Nielzirn & Cesarec, 1981). For females, adults show stronger music emotion perception than children, while males show no significant differences (Robazza et al., 1994). Thus, age-gender interactions may affect the classical music-cognition relationship, though no music studies have examined this interaction, which this study will explore.

**1.5.2 Gender × Task Type** Classical music' s effects may differ by gender and task type. First, gender differences exist across various cognitive tasks (Upadhayay & Guragain, 2014), with different genders excelling at different tasks: men outperform women on visuospatial and mental rotation tasks (Voyer et al., 2017; Wang et al., 2013), while women excel in language, reading, and memory (Halpern, 2012; Loprinzi & Frith, 2018; Stoet & Geary, 2013), possibly related to brain structure, sex hormones, and stereotypes (Miller & Halpern, 2014). Moreover, music' s cognitive facilitation shows gender differences: music improves women' s attention, memory, and reading comprehension (Rizou, 2020; Wu & Shih, 2021) but distracts men and slows their responses on attention tasks (Jing et al., 2012), while music improves men's performance on motor tasks (e.g., Purdue Pegboard Test[3]) but not women' s (Nobre et al., 2018; Rodriguez-Negro et al., 2021; Taheri et al., 2022). Previous studies have not comprehensively examined task type-gender interactions, which this study addresses.

[3] The Purdue Pegboard Test, designed by Tiffin in 1948, uses a board with 4 grooves and two rows of holes, plus pins, washers, and collars. Participants insert pins into corresponding holes using right hand, left hand, and both hands separately for 30 seconds each. The dependent variable is the number of pins inserted, with three trials per task averaged for final scores. This test reflects overall hand/arm motor function and finger dexterity with good reliability and

validity.

**1.5.3 Gender × Dominant Hemisphere** Classical music' s cognitive benefits may be influenced by the interaction between gender and cerebral hemispheres. First, gender differences exist in hemispheric lateralization (Weiss et al., 2003): in visuospatial tasks, women show more right-hemisphere lateralization while men show more bilateral activation; for speech tasks, men show more left-hemisphere lateralization while women show bilateral activation (Clements et al., 2006). Brain imaging studies also show that in pitch processing tasks, men show more left-hemisphere activation while women show bilateral activation (Gaab et al., 2003), possibly related to corpus callosum size differences, with women showing higher inter-hemispheric connectivity (Preis et al., 1999). Additionally, music emotion valence judgment relates to gender, with different brain activation patterns: for music-evoked negative emotions, women show bilateral brain activation while men show right-hemisphere activation (Altenmuller et al., 2002), possibly because women experience more emotional changes and higher openness than men when processing auditory stimuli like music (Koelsch et al., 2003). This study further examines gender-hemisphere interactions.

**1.5.4 Gender × Culture** Classical music' s effects may also be moderated by the interaction between gender and culture. First, cognitive gender differences show cross-cultural variation (Miller & Halpern, 2014): some countries show no math gender differences, while a few show female advantages (Reilly, 2012; Stoet & Geary, 2013); reading and mental rotation gender differences vary across nations (Penner & Paret, 2008; Reilly, 2012). Cross-cultural research also shows music emotion perception gender differences vary by culture (Lee & Hu, 2014), with cultural differences playing a more important role in female listeners' music emotion judgments than in males (Hu & Lee, 2016). As Western classical music, Mozart may be more familiar to Western participants, and women show advantages in recognizing familiar melodies (Miles et al., 2016), potentially causing gender-cultural differences in music emotion perception that affect cognitive performance. Therefore, this study examines gender-culture interactions.

In summary, this study investigates whether listening to classical music promotes cognitive task performance based on the generalized Mozart effect, explores factors causing divergent research findings, and compares the two mechanistic theories to help people view classical music' s effects objectively, clarify the Mozart effect mechanism, and provide theoretical and practical guidance for music education.

### 2.1 Literature Search and Screening

We searched English databases (Web of Science, PubMed, ProQuest) using keyword combinations ( "Mozart effect" OR "Mozart music" OR "music effect" OR "classical music" ) AND (cognit* OR intellig* OR spati*), supplemented by Google Scholar. Chinese databases (VIP, Wanfang, CNKI, Chaoxing, Chinese

Master' s and Doctoral Dissertation Full-text Databases, Baidu Academic) were searched using ( "莫扎特效应" OR "莫扎特音乐" OR "古典音乐" OR "音乐效应" ) AND (认知 OR 智力 OR 空间). We also manually searched references from reviews and related articles. The search covered January 1993 to September 2022, retrieving 2,057 documents. The screening flowchart is shown in Figure 2 [Figure 2: see original paper].

### 2.2 Inclusion and Exclusion Criteria

Literature was screened according to these principles: (1) studies must contain complete data for experimental (listening to classical music) and control (listening to other music/sounds or silence) groups; (2) studies must involve the generalized Mozart effect and cognitive performance; (3) participants must be general populations, excluding clinical patients and animal studies; (4) studies must be in Chinese or English; (5) sample sizes must be clearly reported. The inclusion/exclusion flowchart is shown in Figure 2 [Figure 2: see original paper].

### 2.4 Data Analysis

We used the "metafor" package in R for meta-analysis. Effect sizes were calculated as standardized mean differences (Hedge' s g) (Vollestad et al., 2012), with small, medium, and large effects defined as 0.20, 0.50, and 0.80 respectively (Cohen, 1992). Positive g values indicate better cognitive task performance in experimental versus control groups. Given diverse cognitive tasks and potential variation across participant age and gender, we used random-effects models. Heterogeneity was assessed using Q and $I^2$ statistics. To explore heterogeneity sources, we conducted subgroup analyses on categorical variables (age group, gender, cultural background, music presentation order, control group type, cognitive task type, dominant hemisphere) and meta-regression on continuous variables (publication year, sample size, study quality). We also examined interactions among participant characteristic and experimental design variables. Regarding the two mechanistic theories, we first identified studies successfully replicating the Mozart effect, then classified those showing brain indicator changes or explicitly supporting direct priming as supporting the direct priming hypothesis, and those involving music-induced emotion/arousal changes as supporting the arousal-mood hypothesis.

To test robustness and identify potential outliers affecting meta-analysis validity, we conducted sensitivity analyses using leave-one-out methods (Morgan et al., 2018) and influence analysis to identify outliers and influential points through difference in fits (DFFITS), Cook' s distances, covariance ratios, hat values, weight estimates, and externally standardized residuals (Viechtbauer & Cheung, 2010). We used funnel plots and fail-safe numbers (Nfs) to test publication bias.

### 3.1 Overall Assessment of Mozart Effect Size

We obtained 91 valid studies with 172 independent effect sizes from 7,159 participants (mean Jadad score = 2.42). The random-effects model showed an overall effect size of 0.44, with significant heterogeneity ($Q(169) = 506.63$, $p < 0.001$, $I^2 = 70.76\%$). Sensitivity analysis showed g values ranged from 0.39 to 0.45 ($p < 0.001$) when excluding any single sample. Influence analysis identified four outlying studies. After removing these outliers, the final effect size was $g = 0.36$ (95% CI [0.24, 0.49], $p < 0.001$), indicating a small but significant facilitative effect of classical music on cognitive performance.

### 3.2 Publication Bias Test

The funnel plot showed effect values concentrated at the top and evenly distributed around the overall effect, suggesting low publication bias risk. The fail-safe number (Nfs = 13,305) far exceeded the critical value (5K + 10, where K = independent effect sizes), indicating no significant publication bias.

### 3.3 Comparison of Effect Sizes for Two Mechanisms

Results for the two mechanisms (Figure 3 [Figure 3: see original paper]) showed: direct priming hypothesis had a large, significant effect ($g = 1.29$, $k = 15$, $p < 0.001$); indirect arousal-mood hypothesis had a small effect ($g = 0.34$, $k = 14$, $p < 0.001$). Some behavioral and neuroscience studies suggest emotion is key in the Mozart effect, with a combined effect of $g = 0.28$ ($k = 12$, $p = 0.036$); other data support arousal' s facilitative role ($g = 0.22$, $k = 9$, $p = 0.104$). The direct priming hypothesis showed a larger total effect size than the arousal-mood hypothesis ($1.29 > 0.34$, $p = 0.045$), receiving stronger support.

### 3.4 Subgroup, Interaction, and Meta-Regression Analysis

To examine sources of effect size heterogeneity, we conducted subgroup, meta-regression, and interaction analyses (Table 2 ). Regarding participant characteristics, subgroup analysis showed significant differences between Chinese and foreign participants, with Chinese participants showing significantly larger effects ($g = 0.64$ vs. 0.27, $p = 0.018$). Gender showed no significant moderating effect ($p = 0.201$). Age group significantly moderated effects ($p = 0.002$), with preoperational children (ages 3-6) showing the largest effect ($g = 1.10$) and adults the smallest ($g = 0.24$). Regarding design features, between-subjects designs showed significantly larger effects than within-subjects designs (g: $0.48 > 0.22$, $p = 0.037$). Right-hemisphere tasks showed significantly larger effects than left-hemisphere tasks (g: $0.44 > 0.08$, $p = 0.019$). Music presentation order ($p = 0.207$), control group type ($p = 0.837$), and cognitive task type ($p = 0.325$) showed no significant between-group differences.

Interaction analyses revealed significant gender × age group interaction ($p < 0.001$): classical music most strongly enhanced cognitive performance in preoperational girls ($g = 2.69$), moderately in preoperational boys ($g = 0.47$), with negligible effects on adult males and females. Additionally, culture × gender interaction was significant ($p = 0.005$): classical music improved Chinese females' performance far more than foreign females, with minimal gender differences among foreign participants. Gender × dominant hemisphere interaction was also significant ($p = 0.036$): for females, classical music significantly facilitated right-hemisphere tasks; for males, left- and right-hemisphere effects were similar. Meta-regression showed Mozart effect size did not vary significantly by publication year, sample size, or study quality (all $p > 0.160$).

### 4.1 Promotional Effect of Classical Music on Cognitive Performance

This meta-analysis confirms the Mozart effect' s existence: classical music significantly improves cognitive performance compared to silence and popular music conditions, consistent with numerous empirical studies (Aoun et al., 2005; Rauscher et al., 1995) and previous meta-analyses (Hetland, 2000; Pietschnig et al., 2010). Researchers have proposed that not all music types produce positive effects. Classical music can enhance spatial reasoning, episodic memory, and other cognitive functions (Ferreri, Bigand & Bugaiska, 2015; Rauscher & Shaw, 1998), even improving autobiographical memory in Alzheimer' s patients (Fang et al., 2017) and aiding cognitive rehabilitation in elderly adults (Cacciafesta et al., 2010; Perlovsky et al., 2013). In contrast, popular music may interfere with cognitive tasks (Furnham & Allass, 1999), possibly related to musical rhythm, pitch range, melodic curves, and note sequences (Mammarella et al., 2007). Evaluation shows classical music improves various cognitive task scores, making people "smarter."

### 4.2 Mechanism of the Mozart Effect

What is the Mozart effect' s mechanism? This study found the direct priming hypothesis effect size significantly larger than the arousal-mood hypothesis, supporting direct priming more strongly, consistent with Rauscher and Shaw (1998). Since studies supporting direct priming primarily observed whether classical music improved spatial cognition, the trion model (Leng et al., 1990) can explain the findings. According to the trion model, listening to music and performing spatial tasks share similar neural firing patterns; music' s neural pattern directly primes spatial processing brain regions, improving spatial reasoning (Rauscher et al., 1995; Rideout et al., 1998). Cognitive neuroscience provides supporting evidence: fMRI and EEG studies show Mozart music activates brain regions related to spatial tasks (Bodner et al., 2001; Suda et al., 2008), induces coherent frontal and temporal lobe activity (Sarnthein et al., 1997), activates cortical function and sympathetic nerves (Lin et al., 2014), increases alpha and gamma band synchronization and alpha power (Verrusio et al., 2015), accompanies spatiotemporal task improvement (Jausovec et al., 2006), and shows gamma power fluctuations related to music perception (Bhattacharya & Petsche, 2001). An ERP study showed classical music (unlike rock) increased N2 amplitude during listening, indicating enhanced pre-attentive processes (Caldwell & Riby, 2007).

Studies using comprehensive cognitive assessments found that 5 minutes of pre-class Mozart music improved elementary students' academic achievement in memory, comprehension, and application by enhancing alpha and gamma waves, stimulating neural networks, and preparing the brain for learning (Mualem et al., 2021). Combined with brain imaging evidence, direct priming explains why classical music facilitates cognition. However, the arousal-mood hypothesis also received some support: listening to music can increase arousal to focus attention or induce positive emotions that facilitate cognition (Thompson et al., 2001). Though its effect size was small (g = 0.34), it reached significance, suggesting arousal-mood may not be the sole mechanism but cannot be excluded.

### 4.3 Moderating Effect of Participant Characteristics

**4.3.1 Age Group and Its Interaction with Gender** Age group significantly moderated effects: classical music most strongly facilitated cognitive performance in 3-6-year-olds and least in adults. This differs from Pietschnig et al. (2010), who only compared children versus adults, a coarse classification that may overlook developmental differences in music cognition and brain plasticity (Hou & Dong, 2010). Compared to adults, young children' s brains are more plastic (Merzenich et al., 2014), with rapid cognitive development during this period (Brown & Jernigan, 2012). The critical period for absolute pitch acquisition is ages 3-6 (Song et al., 2020), and brain volume reaches 95% of peak by age 6 in both sexes (Giedd & Rapoport, 2010). Longitudinal studies show two years of music training (string instrument playing) for school-age children (6-7 years) causes brain structural changes (Habibi et al., 2018), such as enhanced corpus callosum connectivity and slowed superior temporal gyrus cortical thinning. Long-term music education significantly facilitates inhibitory ability, planning, and verbal intelligence in school-age children (Jaschke et al., 2018).

Interaction analysis showed significant gender × age group interaction ($p < 0.001$): classical music most strongly enhanced preoperational girls' performance (g = 2.69), moderately for preoperational boys (g = 0.47), with negligible effects on adults. Most effect sizes for 3-6-year-olds involved spatial cognition tasks. This can be explained by age-related changes in spatial cognition gender differences. Evolutionarily, males' hunting activities gave them spatial advantages (Ruigrok et al., 2014), but girls have the greatest potential for improvement and may improve fastest with spatial training (Xu & Zhang, 2000), making them more malleable and thus more responsive to classical music. Working memory span studies also show girls outperform boys under classical music conditions (Gu, 2021), possibly because girls prefer classical music styles, making them more patient during tasks (Ruan, 2007).

**4.3.2 Cultural Differences and Interaction with Gender** Previous research suggests people have special preferences for music from their own culture (Juslin & Sloboda, 2011), and cultural congruence can enhance arousal and attention (di Muro & Murray, 2012; Zhu et al., 2009), improving cognitive performance (Demorest et al., 2008; Mohan & Thomas, 2020). However, this study found classical music' s facilitative effect was significantly stronger for Chinese than foreign participants, contrary to previous findings. One explanation involves music familiarity effects: familiar music may distract participants, making concentration difficult (Perham & Vizard, 2011) and impairing memory (Perham & Sykora, 2012). Foreign participants may be more familiar with classical music, potentially causing distraction through memory and association (Dai & Marshall, 2021; Ferreri, Bigand, Bard et al., 2015), resulting in smaller effects for Chinese participants—consistent with Perham et al. (2012). Additionally, culture × gender interaction significantly moderated the relationship: classical music most strongly enhanced Chinese females' performance, possibly because women participate more in music activities and prefer classical music (Suh & Park, 2011), experiencing greater pleasure and happiness with stronger EEG responses than men (Díaz et al., 2011).

### 4.4 Moderating Effect of Experimental Design Features

**4.4.1 Cognitive Task Type, Hemispheric Function, and Interaction with Gender** This study found cognitive task type did not significantly moderate the classical music-cognition relationship. However, when tasks were categorized by dominant hemisphere, hemisphere showed significant moderation, with right-hemisphere tasks showing significantly larger effects than left-hemisphere tasks. This aligns with empirical research (Aheadi et al., 2010; Overman et al., 2003) and supports the hemispheric-activation hypothesis. Since music and spatial tasks activate the same hemisphere, and one hemisphere' s activation relates to reduced activity in the other (Kinsbourne, 1974), spatial tasks closely related to right-hemisphere function may benefit from music activation, while left-hemisphere tasks (e.g., reading, math) may be negatively affected (Dong et al., 2022; Kaempfe et al., 2011). Neuroscience research shows Mozart music activates right parietal regions, improving spatial performance (Rauscher et al., 1995); non-musicians show greater right-hemisphere activation during music listening accompanied by mental rotation improvement, while musicians show no lateralization (Aheadi et al., 2010). Thus, music' s effects may not apply to all cognitive processes and may differ by cognitive nature. This study preliminarily suggests listening to classical music may improve right-hemisphere task performance but is not recommended for left-hemisphere tasks.

Task type × gender interaction was non-significant, possibly because cognitive development gender differences remain controversial. While many studies confirm such differences (Ruigrok et al., 2014), others suggest they are minimal and appear only in few tasks (Ardila et al., 2011). This study' s broad cognitive scope may have weakened gender differences. However, hemisphere × gender interaction was significant: for females, classical music significantly facilitated right-hemisphere tasks; for males, left- and right-hemisphere effects were similar. Since right-hemisphere tasks in this study were spatial, classical music optimally shaped females' spatial cognition. Although males generally show spatial advantages (Doyle & Voyer, 2016; Lei & Liu, 2014), boys' right-hemisphere specialization for spatial information emerges around age 6, while girls' specialization appears during adolescence (Bian, 2013). Males' advantages weaken with age, while females, though "late maturers," improve faster, potentially explaining classical music' s greater impact on girls' spatiotemporal reasoning (Wu et al., 2014). Additionally, while women tend to use verbal strategies, complex music may shift them from left-hemisphere language encoding to right-hemisphere resource encoding (Mcguinness et al., 1990), enhancing right-hemisphere function (Gilleta et al., 2003). Women may also experience task anxiety during spatial tasks due to stereotype threat (Doyle & Voyer, 2016), and music may relax them and facilitate performance (Panteleeva et al., 2018).

**4.4.2 Experimental Design Type** Design type significantly moderated effects, with between-subjects designs showing significantly larger effect sizes than within-subjects designs. Rauscher and Shaw (1998) suggested experimental factors like measurement tools, stimulus presentation order, and procedures could affect results, cautioning against pre-post designs because pre-tests create carryover effects that mask performance improvements. Music perception is innate (Lai et al., 2013), and music is an emotional language and artistic form of emotional communication (Krumhansl, 2002); music expresses and evokes emotions (Yang et al., 2022). In Mozart effect experiments, experimental music listening inevitably activates brain networks, processing musical structure and experiencing emotions (Schaerlaeken et al., 2019). Different music valence and arousal activate different brain regions, and music experiences involve reward, memory, self-reflection, and sensorimotor processing (Chen & Wen, 2017), persisting over time and affecting subsequent tasks, thus weakening pre-post differences. Additionally, within-subjects designs without adequate inter-condition intervals can cause fatigue effects (Anderson, 2002), weakening classical music' s facilitative effects. Therefore, within-subjects designs should include sufficiently long distractor tasks between music and control conditions to eliminate carryover effects, or use intervals over 24 hours, or preferably adopt between-subjects designs.

**4.4.3 Music Presentation Order** Music presentation order showed no significant moderating effect. Previous research suggested background music occupies cognitive resources and increases load (Nemati et al., 2019; Wahn & Koenig, 2017), while pre-task music does not, but this study found no significant difference between pre-task and background music conditions, inconsistent with some studies (Rey, 2012; Shek & Schubert, 2009). One explanation is that pre-task music stops before tasks begin, reducing distraction but also weakening music' s brain reward effects (Silva et al., 2020). Another explanation is that background music' s interference depends on task difficulty and complexity. For simple tasks, background music may be beneficial by increasing arousal or enjoyment (Levinson et al., 2012), enhancing attention for tasks with low sustained attention demands (Kiss & Linnell, 2021). Complex tasks require focused attention, and background music can distract and impair performance (Gonzalez & Aiello, 2019), interfering with memory and reading comprehension (Du et al., 2020). Since only one study in our sample manipulated task difficulty under background music conditions, and our tasks were broad without clear difficulty classifications, we could not analyze music presentation order × task difficulty interactions. Future research should consider task characteristics when determining whether music should be listened to before or during tasks.

**4.4.4 Control Group Type** Classical music versus silence, non-music, folk music, and popular music all showed positive effects, indicating overall facilitative effects on various cognitive performances. Classical music versus silence showed a relatively large effect (g = 0.38), suggesting classical music generally facilitates rather than interferes with attention. Notably, this result is based on 109 independent effect sizes and thousands of participants, making it more representative and reliable than previous meta-analyses. To clarify which musical emotion type is more effective, we separately analyzed studies explicitly categorizing classical music emotion types, finding positive-emotion classical music versus silence showed a large effect (g = 0.93), while negative-emotion classical music versus silence showed a small effect (g = 0.24), indicating cheerful, pleasant classical music better facilitates cognition, consistent with positive emotion research (Chen et al., 2022) and validating the Broaden-and-Build Theory of Positive Emotions (Johnson et al., 2010).

Compared to popular music, classical music facilitated cognition (g = 0.34), with little difference between popular music with lyrics (g = 0.41) and without (g = 0.43). In contrast, compared to Chinese folk music, classical music showed no significant advantage (g = 0.10). This may be explained by structural and comprehensibility differences between music types. Classical music emphasizes structural beauty, with melodic, harmonic, phrase, textural, and dynamic elements achieving perfect balance, reflecting musical rigor and rationality. Popular music is typically simple, short, and accessible, with structural differences between the two types (Zhang, 2020). Listeners must fully engage senses and imagination, sometimes requiring musical cultivation, to understand classical music' s emotions and meaning. Studies suggest Mozart K.448 improves spatial ability through its rhythm (Xing et al., 2016). Classical music more strongly activates the brain than popular music (Bhattacharya & Petsche, 2005). Although Western music uses heptatonic major/minor scales while Chinese folk music uses pentatonic scales (gong, shang, jiao, zhi, yu), these modes express similar emotions (Yang et al., 2022). Both forms have rigorous structures, emphasize melodic development, and require higher brain engagement for understanding. These similarities may explain why classical music showed no advantage over Chinese folk music.

### 4.5 Research Significance and Limitations

This study examined the generalized Mozart effect, systematically evaluating classical music' s facilitative effects on cognitive performance, its mechanism, potential moderators, and their interactions. Encompassing rich music and task types, it addresses limitations of previous meta-analyses and helps answer "Does listening to classical music make you smarter?" Theoretically, it clarifies debates about the Mozart effect' s reliability and scientific status, providing a foundation for deeper exploration. It is the first to compare direct priming and arousal-mood hypotheses, revealing the former' s greater explanatory power and guiding future interdisciplinary research on music-cognition relationships. Practically, findings show classical music' s effects are constrained by multiple factors (most pronounced in female children, varying by cerebral hemisphere), providing guidance for music education and therapy, particularly for child cognitive development. This cautions against commercially-driven Mozart effect hype and encourages rational examination of classical music' s cognitive impacts.

Limitations include: (1) We only tested short-term effects; long-term effects remain unclear. (2) While examining mechanisms, we could not reach definitive conclusions. Some research suggests music preference-induced arousal facilitates cognition, but few included studies measured preference, leaving this unverified. (3) Some potential moderators (personality traits, music familiarity, task difficulty) could not be analyzed due to insufficient data. Future research should explore these variables with richer data.

In conclusion, this meta-analysis found: (1) Classical music has a small facilitative effect on cognitive performance (g = 0.36); (2) Both direct priming and arousal-mood hypotheses received support, with direct priming showing larger effects; (3) Age, cultural background, design type, and cerebral hemisphere moderate the Mozart effect; (4) Gender interacts with age, culture, and hemisphere. These findings advance understanding of music-cognition relationships and inform educational applications.

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

*Source: ChinaXiv —Machine translation. Verify with original.*