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Research Reports

Executive Functions and Music Training: A Meta-Analysis

Exekutive Funktionen und musikalisches Training: Eine Meta-Analyse

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Supplementary Materials: Data, Materials [see Index of Supplementary Materials]

Abstract

Executive functions (EFs) are cognitive functions that enable goal-directed behavior. The most frequently studied EFs are working memory, inhibition, and cognitive flexibility. A meta-analysis was conducted to investigate possible relationships between EFs and music training and to estimate the magnitude of such relationships. The meta-analysis included studies that examined at least one EF in connection with music training. Studies were identified in accordance with PRISMA guidelines. After identifying 72 studies as relevant for the meta-analysis, these were classified into the three main facets of EFs, with some studies considering more than one facet. 45 studies compared the working memory of persons with and without music training, 22 studies provided such a group comparison for cognitive flexibility, and 23 studies reported a group comparison for inhibition. Sixteen studies evaluated correlative findings between the duration of music training and EFs. The meta-analyses revealed a significant advantage for the groups with music training across all three facets of the EFs (g = 0.59). When considered separately, a significant influence of music training emerged for studies investigating working memory (g = 0.69), cognitive flexibility (g = 0.51), and inhibition (g = 0.43). The effects for cognitive flexibility and inhibition were smaller in size than for working memory and less frequently assessed. The correlational studies revealed smaller, yet positive correlations with music training (g = 0.16). Overall, the meta-analysis confirms an advantage for musically trained individuals in performing tasks that measure EFs, without causal effects being able to be derived from the cross-sectional studies used.

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Keywords

executive functions, music training, meta-analysis, working memory, inhibition, cognitive flexibility

Zusammenfassung

Exekutive Funktionen (EFs) sind kognitive Funktionen, die zielgerichtetes Verhalten ermöglichen. Zu den am häufigsten untersuchten EFs zählen das Arbeitsgedächtnis, die Inhibition und die kognitive Flexibilität. Um mögliche Zusammenhänge zwischen EFs und musikalischem Training zu untersuchen und die Größe solcher Zusammenhänge schätzen zu können, wurde eine Meta-Analyse durchgeführt. In diese Meta-Analyse gingen Studien ein, die mindestens eine EF in Verbindung mit musikalischem Training untersucht haben. Die Identifikation von Studien folgte den PRISMA-Richtlinien. Von den zunächst als relevant identifizierten 72 Studien verblieben nach der Aufteilung auf die drei Konstrukte und der Kodierung der Effektstärken 45 Studien, in denen ein Gruppenvergleich zwischen Menschen mit und ohne musikalisches Training in Bezug auf Arbeitsgedächtnis vorlag. 22 Studien lieferten einen solchen Gruppenvergleich für die kognitive Flexibilität, während 23 Studien einen Gruppenvergleich für Inhibition berichteten. In 16 Studien konnten korrelative Befunde zwischen der Dauer des musikalischen Trainings und EFs ausgewertet werden. Die Meta-Analysen ergaben über alle drei Facetten von EFs einen signifikanten Vorteil der Gruppen mit musikalischem Training (g = 0.59). Analysen der einzelnen Komponenten zeigten den größten Effekt für Arbeitsgedächtnisleistungen (g = 0.69). Für Inhibition (g = 0.43) wie auch kognitive Flexibilität (g = 0.51) wurden signifikante Effekte in der angenommenen Richtung gefunden; diese waren allerdings kleiner, und diese Facetten wurden auch seltener getestet. In den korrelativen Studien ergaben sich insgesamt kleinere, positive Zusammenhänge mit musikalischem Training (g = 0.16). Insgesamt bestätigt die Meta-Analyse einen Vorteil musikalisch trainierter Personen bei der Bearbeitung von Aufgaben, die EFs messen, ohne dass aus den verwendeten Querschnittsstudien kausale Effekte abgeleitet werden können.

Schlüsselwörter

exekutive Funktionen, musikalisches Training, Meta-Analyse, Arbeitsgedächtnis, Inhibition, kognitive Flexibilität

Ever since the publication of a short article by Rauscher et al. (1993), which reported an improvement in spatial reasoning after listening to a Mozart sonata for 10 minutes, the question of possible transfer effects of music training has not only been taken up in research, but also in educational contexts (Schellenberg & Lima, 2024). While Rauscher et al. (1993) focused on the effects of music listening, the question of transfer from instrumental training to cognitive function seems intuitively more plausible (Schellenberg & Lima, 2024), as making music is a complex activity that requires intensive training (Ericsson et al., 1993). Genuine transfer in the sense of a causal effect of music training on cognitive abilities can be demonstrated only through experimental studies. Beyond the question of causality, however, it also makes sense to ask how strong the correlations between music training and cognitive abilities are and whether there are variables that influence these correlations (Schellenberg & Lima, 2024). Besides the assumption of

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transfer, it is also conceivable that existing dispositions, such as memory skills, favor the acquisition of musical training (Silas et al., 2022) and that environmental factors, such as socioeconomic variables, moderate this process (Silas et al., 2022). In this paper, we are not pursuing an educational interest in the question but rather want to focus on a domain of cognitive abilities that has been less prominent in the scientific debate on transfer effects than, for example, intelligence. In psychological research about cognitive processes, there is a set of mental functions which is referred to as executive functions (EFs). These are required when goal-directed behavior, problem solving, or monitoring of performance is needed. Put differently, EFs become relevant whenever relying on automatic behavior or giving in to distractions would have negative consequences for an individual. It could be argued that EFs are "critical for many of the skills that most people would agree will be important for success in the twenty-first century – such as creativity, flexibility, self-control, and discipline" (Diamond, 2013, p. 155). According to Schellenberg and Lima (2024), it makes intuitive sense to assume an impact of music training for the development of EFs, since self-regulation, flexibility, attention, inhibitory control, and planning and implementation of goal-directed behaviors are required when making music. Music training is thereby understood as an active training in making music which is practiced over a longer period of time. The aim of this paper is to provide a meta-analysis of research on the relationship between music training and EFs.

Please note that this paper is limited to behavioral research. There is a growing body of research on differences in the brain structure between musicians and non-musicians that can be interpreted as an adaptation of auditory and motor regions of the brain to the demands of long-term musical practice (e.g., Penhune, 2019). Whether such differences in brain structure are connected to differences in general cognitive abilities is an interesting question that goes beyond the scope of this meta-analysis.

We will first provide an introduction on the core EFs and summarize existing reviews and meta-analyses, before explaining the method and results of our meta-analysis.

Executive Functions

Diamond (2013) provided a comprehensive review of EFs including a description of the core EFs, possible commonalities and differences between the subcomponents, as well as representative psychological tasks to assess these. The three most widely researched EFs (Diamond, 2013; Miyake et al., 2000) are inhibition, working memory, and cognitive flexibility, which we introduce with reference to music making:

Working memory (WM) refers to processes of maintaining information in mind and mentally updating this information (Diamond, 2013). WM is important for stimuli that unfold over time (Diamond, 2013), such as language or music, because WM enables us to relate later passages of music to earlier ones and keep track of regularities and variations. A typical task for measuring WM in experiments is the backward digit span task, in which digits previously presented must be reported in reverse order. Another WM task

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is the complex span task (Conway et al., 2005) in which participants must maintain information (e.g., a series of letters) while performing another task interspersed to letter encoding (e.g., judging the correctness of an equation, see Table S1 in the supplemental material for a graphical depiction of the tasks used).

Inhibition or *inhibitory control* subsumes the control of attention, the inhibition of unwanted thoughts or behavior, or the delay of gratification (Diamond, 2013). An example for inhibitory control of attention in music is that we can choose voluntarily to ignore particular stimuli (such as the rhythm of a specific instrument) and attend to other stimuli (such as the rhythm of one's own instrument) based on our goals (Diamond, 2013). An experimental task for measuring inhibition is the Stroop task, in which participants must name the font color in which words are written. This involves inhibitory control as all presented words are color words, i.e., the meaning of the word (e.g., "red") must be ignored when asked to focus only on classifying the font color (e.g., green).

Cognitive flexibility builds on inhibition and WM (Diamond, 2013) and involves the ability to adjust to changing demands in thoughts or actions. An instrumentalist, for example, must adjust the fingering of a note when an accidental precedes it (i.e., changing an F to an F#), or when the clef has been changed from bass clef to treble clef (Slama et al., 2017). In experiments, cognitive flexibility is often measured with task-switching requirements (see Kiesel et al., 2010, for a review). A typical switching task involves an instruction on changing task demands, i.e. alternating between two types of stimuli as in the trail making test. In this task, letters and digits must be connected in ascending order, thereby constantly switching between considering letters and digits.

In their *unity and diversity* approach, Friedman and Miyake (2017) argue that the three above mentioned core EFs are commonly tested separately by experimental procedures but are also correlated with one another on the level of latent variables that extract shared variance (Miyake et al., 2000), thereby motivating to treat them as unique yet related set of cognitive functions (Aryanto et al., 2026). The question of how to model individual differences in EF components is still debated in cognitive psychology (Friedman & Miyake, 2017) and will not be discussed in detail here. Given that distinct task requirements exist (in experimental procedures as well as in the examples given for the music domain) we decided to first examine the three core EFs in a joint analysis across all three components and then analyze each component separately, taking moderators into account. These separate analyses provide a more fine-grained picture of the impact of music training on particular cognitive functions whereas the question remains to be answered whether executive functions as an overarching construct (like the *g-factor* in intelligence) really exists (Aryanto et al., 2026; Friedman & Miyake, 2017; Rey-Mermet et al., 2019).

Although this paper does not test the causal assumption of a transfer effect, it is nevertheless important to note that EFs can be improved at any age throughout the

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lifetime, while it is still unclear which specific conditions lead to long-term effects (Diamond, 2013; Valian, 2015).

Executive Functions and Music Training: Existing Reviews and Meta-Analyses

While there is little doubt that EFs are required for both music listening and music making (Degé & Frischen, 2022), there is ongoing research on the question of potential relationships between music training and EFs. Since EFs can generally be trained in children (Diamond & Lee, 2011), the question arises as to whether music training (which often starts during childhood) can lead to improved EFs (i.e., a transfer effect, Jaeggi et al., 2011). The reason for any transfer effects could be that making music is a complex activity that builds on a wide range of cognitive abilities (Schellenberg & Lima, 2024). Musicians practice translating complex musical notation into sound, often in groups, so that social aspects must be considered in addition to cognitive aspects (Degé & Frischen, 2022). Degé and Frischen (2022) argue that playing music combines the aspects identified by Diamond and Lee (2011) for successful training of EFs: it is engaging for one's own interests, it often takes place in social groups, and it is challenging. On the other hand, it is also possible that better EFs lead to successful music training. The question of possible transfer effects can only be answered conclusively by experimental studies, while correlations between tasks used to measure EFs and music training have also been investigated by individual differences studies comparing participants with varying levels of music training. There are a few review papers on EFs and music training which are summarized below.

Degé and Frischen (2022) presented a systematic review on longitudinal studies with children below the age of 11 years. They reported 21 samples, 20 of which had a positive effect of music training on at least one EF (no mean effect sizes were reported in this systematic review). On the other hand, a large meta-analysis by Sala and Gobet (2020) on cognitive and academic benefits of music training in children aged 3 to 16 years found an overall null effect (g = -0.021–0.064) for studies using active controls or implementing random assignment of participants, regardless of the type of outcome measure (i.e., no positive effect was found for any EF).

Román-Caballero et al. (2018) suggested that age-related cognitive decline which often becomes visible around the age of 60 might be reduced in persons with a history of music training. They presented a systematic review and meta-analysis on nine correlational and four experimental studies on cognitive function in adults above the age of 58 years. Correlational studies identified positive effect sizes in favor of the musically trained groups on all cognitive functions (standardized mean difference [*SMD*] = 0.316 for processing speed, *SMD* = 0.441 for attention, *SMD* = 1.766 for inhibition, *SMD*s between 0.180 and 1.660 for more complex functions such as verbal memory), including

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a few samples on EFs. The experimental studies included short-term music training between four to six months and reported a positive effect size for flexibility (*SMD* = 0.93).

Reviewing studies with adult samples, Talamini et al. (2017) provided a meta-analysis of 29 memory studies including long-term memory, short-term memory, and WM. The meta-analysis reports a positive effect of music training on WM (g = 0.56). The musicians' advantage in WM measures was large with tonal stimuli (g = 1.04), moderate with verbal stimuli (g = 0.59), and null with visuospatial stimuli (g = 0.01).

A paper that comes close to our own objective is that of Pérez-Eizaguirre et al. (2023). They reviewed data from 16 papers on EFs, memory, and intelligence, which included altogether 92 independent samples. Among these, 37 samples deal with EFs. The authors found a positive mean effect size of g = 0.37 for EFs and a moderating effect of the duration of music training, with larger effect sizes being associated with a shorter duration of music training. This somewhat odd result is explained as reflecting an effect of age when starting the training as young children have least training but show strongest effects (Pérez-Eizaguirre et al., 2023).

Another paper that comes close to our own objective is the recent systematic review and meta-analysis by Aryanto et al. (2026) on the associations between musical expertise and EFs. Their analysis included 47 studies published up to 2020 with adult participants and they report a mean effect size of g = 0.43 for associations between musical expertise and EFs as latent construct, as well as significant associations between musical expertise and inhibition (g = 0.31), musical expertise and shifting (g = 0.22), and musical expertise and WM (g = 0.49). Among several potential moderator variables, the authors found that only risk of bias was a significant moderator of the association between musical expertise and inhibition, while for all other moderators, the evidence was non-significant or ambiguous (Aryanto et al., 2026).

In sum, the available studies for child samples show a transfer effect of music training on executive functions in longitudinal studies (Degé & Frischen, 2022), but no group differences between children with and without music training (Sala & Gobet, 2020). In older adults, both correlative and causal effects on EFs have been demonstrated (Román-Caballero et al., 2018), although the effects in older adults were smaller than in younger adults in the analysis of Pérez-Eizaguirre et al. (2023). The analysis by Aryanto et al. (2026) underlines the importance of differentiating between types of EF and reports a slightly higher effect size than Pérez-Eizaguirre et al. (2023) for the non-differentiated view on EFs. In our own analysis, we aim to provide additional evidence on the association between music training and EFs on potential moderating variables for this association by expanding the selection of studies to include gray literature as well as studies up to 2025. The following section explains our selection process and statistical analyses.

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Method

We based the search for and selection of articles on the PRISMA guidelines for reporting systematic reviews (Page et al., 2021; see also https://www.prisma-statement.org).

Study Selection

Literature Search

The electronic databases APA PsycInfo, Web of Science, and RILM Abstracts of Music Literature were the primary sources for our literature search. As search terms, we used a combination of "executive function" OR "executive control" OR "inhibition" OR "planning" OR "shifting" OR "cognitive flexibility" OR "working memory" AND "music training" OR "music lesson" OR "music intervention". In addition, the Social Science Research Network (SSRN), ProQuest Dissertations and Google Scholar were searched with the same search terms to identify gray literature as well. To obtain unpublished data, a call for submissions was published in the newsletter of the German Society for Music Psychology. Furthermore, we screened the above-mentioned meta-analyses and added missing papers to provide true incremental research. The last update for our search was done on March 17, 2026. We identified 824 records which were entered in the process of study selection.

Inclusion and Exclusion Criteria

Our review includes studies that include at least one EF measurement as well as an assessment of music training that differed between two groups of participants. We included only studies with a minimum amount of one year of music training. There were no restrictions as to the type of music training, but we excluded all studies that involved music therapy instead of music training. Concerning study designs, we included both cross-sectional and correlational studies but excluded meta-analyses and training studies. We restricted our analysis to samples of healthy adults. Consequently, our exclusion criteria were studies with child samples or clinical samples. Formal inclusion criteria were that the studies be published in English and that relevant data points to be included in the meta-analysis were provided or shared upon request.

Selection of Studies

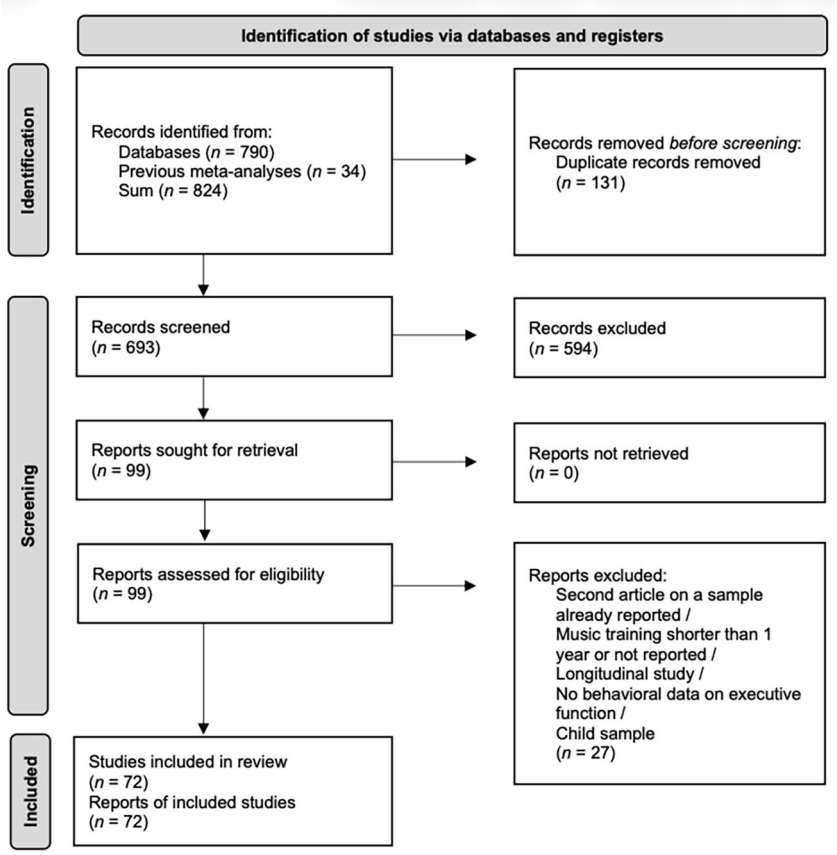
The first step after the literature search was to enter all 824 records into the software Rayyan (https://www.rayyan.ai/), which was used for the removal of duplicates and the screening process. After the removal of 131 duplicates, we entered 693 records into the first screening process. Both authors independently reviewed all titles and abstracts and decided whether they met the criteria. Cases with divergence in judgment were discussed between the authors and led to a consensual agreement. This step resulted in the exclusion of 594 records. The remaining 99 studies were included in the full-text

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screening, which was again done by both authors independently. During the full-text screening, we excluded further 27 studies which did not meet the inclusion criteria. This resulted in a total of 72 studies which were included in the present meta-analysis. Figure 1 shows the selection process as flow diagram.

Figure 1

PRISMA Flow Diagram for the Selection Process of Studies for the Meta-Analysis



Coding Process

The basic information on all studies was coded (by first author, reviewed by second author and discrepancies were solved by discussion) into a data base. The following information was recorded: study design (group comparison, correlational study), sample size, mean age of participants, type of music training, construct EF (inhibition, cognitive flexibility, working memory, other), inferential statistical outcomes, effect sizes. Studies

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including more than one construct of EFs were considered for the analyses with all respective data points but segmented into constructs for reporting (see Tables 2 to 5). This ensured that no information was lost and suited the chosen statistical approach of a multilevel regression in which effect sizes are nested in studies (comparable to a repeated measurement design; Baayen et al., 2008; Gade et al., 2021; Viechtbauer, 2010). Given that the included studies used different tasks to measure each EF (see Table 1 and Table S1), we coded task as well and added it as categorical moderator to the analysis.

Table 1

Core Constructs of EFs and Experimental Test Procedures for Measuring Each Construct

Inhibition / Interference Control / Selective Attention	**Working Memory / Updating**	**Cognitive Flexibility / Switching / Set Shifting**
Stroop	Corsi Block Tapping (CBT) or Corsi Block Tapping backwards	Trail Making Test A/B (Trails)
Color Word Interference	N-back Task (e.g. 2-back)	Fluency tasks, e.g. design/verbal/ semantic fluency
Simon	Backward Digit Span	Numerical Set Switching or Numerical Task Switching
Stop-Signal	Reading Span	Wisconsin Card Sorting Test (WCST)
Flanker	Operation Span	Perceptual Set Switching
Attentional Network Test (ANT)	Digit Span (WAIS)	
Go/No-Go	Spatial Span (Wechsler)	
Anti Saccade	Wechsler Memory Scale Working Memory Index (WMS WM Index)	
Integrated Visual and Auditory Plus Continuous Performance Test	Dual-task Sentence Processing	
	Letter Number Sequencing (LNS)	
	NIH Toolbox Sorting WM	
Controlled Oral Word Association Test (FAS)	Visual Pattern Test Active (VPTA)	
	Auditory WM (AWM)	
	Visual WM (VWM)	
	Jack and Jill Task	

Note. A description of these testing procedures can be found on OSF (Table S1).

After categorizing the studies, the descriptive data from each study was retrieved. If this information was not provided in the manuscript, the original authors of the respective study were asked if they could provide it. The coding process revealed that most studies

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used group comparisons (with and without music training), while there were also 16 correlational studies. Due to the small number of correlational studies, we averaged across the specific components assessed. For the group comparison studies (n = 56), we considered the three core EFs and abandoned the small number of samples reporting "other" EFs such as planning. Table 2 presents the 16 correlational studies included in the meta-analysis, Table 3 presents the 45 studies for the meta-analysis of WM tasks, Table 4 presents the 22 studies for the cognitive flexibility tasks, and Table 5 presents the 23 studies for inhibition tasks.

In addition to the descriptive data, the following potential moderators were considered for further analyses: The duration of music training was coded as high or low (median split) following our assumption that longer music training would have a larger effect than shorter music training. Since all EF facets were measured by several different tasks, we coded tasks into a frequent task (the one most frequently used task, e.g. the Stroop task for inhibition) vs. other (less frequently used) tasks. As the identified studies differed in terms of the age group, we coded the mean age of the participant group into young (below mean age of 40 years) vs. old (above mean age of 60 years) to test for an effect of age. Additionally, we coded the modality of the cognitive test into auditory or visual.

Finally, the risk of bias was coded for each study by adapting the codebook used by Aryanto et al. (2026). We included the following four variables as theoretically interesting and well enough documented to be assessed: 1. risk of bias caused by the matching of participant groups, 2. risk of bias caused by failure to consider confounding variables, 3. risk of bias caused by poor measurement of cognitive functions, 4. risk of bias caused by poor measurement of music training. The four potential moderators as well as the four risk of bias variables were coded independently by both authors. A sum score for the four risk of bias variables was calculated and used as a fifth potential moderator (see coding protocol on OSF for details). Descriptive data, effect sizes, and the coding of moderators and risk of bias variables of all included studies are available on OSF.

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Table 2

Correlational Studies Included in the Meta-Analysis, Characterized by Sample Size, Participants' Mean Age, Definition of Music Training (MT), and EF Task Used in the Respective Study

Author(s), Year	Sample size	Participants' age	Definition/Test of Music Training	Construct EF, Tasks
Cui et al. (2025)	65	21.3	Gold-MSI music training scale	WM: visuospatial memory (WMS-IV)
Fernández-Rubio et al. (2024)	77 (37 young, 40 old)	21.89 (young), 67.50 (old)	Gold-MSI	WM: Digit Span
Frischen et al. (2022)	136	22.1	Total MT = years of music lessons + years of playing in a musical group; age of MT start	WM: N-Back Task Cognitive flexibility: Set Shifting Task Inhibition: Go/No-Go
Fu and Evans (2025)	39	24.5	Gold-MSI music training scale	WM verbal: Reading Span, WM melodic: adaptive melodic discrimination test
Gade and Schlemmer (2021)	49	21.6	Gold-MSI music training scale (sum of 5 items)	Cognitive flexibility: task-switching, assessment of switch costs, n-2 repetition costs
Kempe et al. (2012)	120	24.0	Musical ability questionnaire	WM: Reading Span; Inhibition: Simon
Kopiez and Lee (2008)	52	24.56	Piano students, self-reported hours of practice	WM: Memory Updating
Kowalewski et al. (2022)	320	19.16	Gold-MSI music training scale, OMSI-rank, music lessons, MCSW (musical contingent self-worth)	WM: Tonal 2-Back Task, Visual 2-Back Task,
Okada and Slevc (2018)	150	19.26	Gold-MSI music training scale	WM: Keep Track, Letter memory, Spatial N-Back Cognitive flexibility: Number-Letter, Color-Shape, Category Switch

Author(s), Year	Sample size	Participants' age	Definition/Test of Music Training	Construct EF, Tasks
				Inhibition: Anti Saccade, Stop-Signal, Stroop
Paap et al. (2020)	201	23.7	Years of MT, frequency of instrument playing	Inhibition: Simon, Spatial Stroop, Vertical Stroop, Flanker
Posedel et al. (2011)	45	18.8	M = 2.6 years of music training	WM: Operation Span
Silas et al. (2022)	148	26.4	Gold-MSI	WM: Backward Digit Span, Memory Updating, Jack & Jill (visuo-spatial WM)
Slevc et al. (2016)	96	20.84	OMSI, Musical Ear Test, M = 4.36 years of music training	WM: N-Back; Inhibition: Stroop, Simon; Cognitive flexibility: Switching task
Vuvan et al. (2020)	234	20.64	Gold-MSI training scale, M = 4.71 years of music training	WM: auditory WM, Symmetry Span, Operation Span
Winston et al. (2022)	88	19.31	Musicianship scale, Harmonic ability was measured with harmonization task.	WM: Backwards Digit Span. Inhibition: Go/No-Go, Stroop, Simon
Wolf et al. (2018)	55	23.1	Gold-MSI general, Melodic Memory test	WM: Memory Updating

Note. All descriptive data necessary for calculating effect sizes are available on OSF.

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Table 3

WM Studies Included in the Meta-Analysis, Characterized by Sample Size, Participants' Mean Age (Separated for M (Musicians) and NM (Non-Musicians), if Applicable), Definition of Music Training (MT), and WM Task Used in the Respective Study

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
Amer et al. (2013)	42 (18/24)	60.12	Music experience M = 19.78 years	CBT
Arndt et al. (2023)	100 (50/50)	30.12 (M); 27.3 (NM)	Ollen Musical Sophistication Index, M = 21.02 years of MT	Operation Span, Spatial Span
Bialystok and DePape (2009)	95 (47/48)	23.8	Instrumentalists, vocalists (classically trained)	Spatial Span Wechsler
Boebinger et al. (2015)	50 (25/25)	27.2	MT start before age of 7, Minimum of 10 years of music experience, still actively playing	Backward Digit Span
Caldwell (2015)	22 (12/10)	20.8 (M); 20.5 (NM)	M = 10.1 years of MT (all flute)	Auditory WM
Cara (2024)	60 (31/29)	23.6	M = 8.25 years in music reading	CBT
Clayton et al. (2016)	34 (17/17)	22.5 (M); 20.47 (NM)	Minimum of 10 years of formal MT, minimum of 5 hours practice /week	Backward Digit Span
Criscuolo et al. (2019)	101 (23/51/27 amateurs)	28.44	> 5 years of music practice, final degree at a music academy or job as musician or music teacher	WMS WM Index

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
D'Souza et al. (2018)	153 (81/72)	22	M = 12 years of formal MT (minimum of 8 years), beginning of training at age 7	Backward Digit Span, Reading Span, Operation Span
Fennell et al. (2020)	52 (30/22)	20.6 (M); 19.7 (NM)	MT minimum of 5 years, current practice, ability to read music	Dual-task sentence processing trials
Franklin et al. (2008)	20 (11/9)	19.53 (M); 19.92 (NM)	MT start at age 10 or younger, minimum of 9 years of continuous MT, current practice	Reading Span, Operation Span
Gagnon and Nicoladis (2021)	190 (91/99)	19.51 (M); 19.71 (NM)	MT minimum of 6 years, beginning age maximal 6 years	Backward Digit Span; Backward CBT
George and Coch (2011)	32 (16/16)	20	MT minimum of 9 years, beginning age maximal 9, still actively studying music	Backward Digit Span, Backward Letter Span
Giovagnoli and Raglio (2011)	42 (21/21)	33.2 (M); 33.4 (NM)	Professional teachers in public music schools	CBT
Grassi et al. (2017)	40 (20/20)	72.25 (M); 72.70 (NM)	MT M = 60.30 years, still actively playing	Backward CBT, VPTA, Listening Span
Grassi et al. (2025)	1200 (600/600)	21.7 (female) 22.8 (male)	MT minimum of 10 years, still actively playing	Visual 2-back Task
Gray and Gow (2020)	60 (30/30)	69.66	M had > 10 years of MT	Backward Digit Span
Groussard et al. (2020)	143 (49/49/45 actors)	47.47 (NM); 47.84 (M); 41.58 (Actor)	Current and regular practice at the moment of the study for	Forward Digit Span

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2026, Vol. 34, Article e245
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Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
			more than 3 years, more than 4 h/week, formal music training	
Hanna-Pladdy and MacKay (2011)	70 (22/21/27 low activity musicians)	69.7 (NM); 69.5 (M low-activity); 70.8 (M high-activity)	Low activity musicians: minimum of 1 year, maximal 9 years of instrumental experience; high activity musicians: minimum of 10 years of instrumental experience and formal music training	LNS
Hanna-Pladdy and Gajewski (2012)	70 (33/37)	68.45 (M); 68.81 (NM)	M = 37 years of MT	Digit Span, Spatial Span
Hansen et al. (2012)	60 (20/20/20 amateurs)	21	Expert: students at the academy of music, amateurs: enrolled in a music course in a folk high school	Backward Digit Span, Backward CBT
Hou et al. (2014)	88 (44 superior pitch identification SPI: 26 early MT, 18 no MT/44 average pitch identification API: 26 early MT, 18 no MT)	20.74 (SPI, early training); 20.27 (API, early training); 20.81 (SPI, no training); 20.46 (API, no training)	SPI: > 80% correct pitch identification; API: 9.52–76.19% correct pitch identification	2-back Task; Digit Span
Jain and Nataraja (2019)	51 (26/25)	33.71 (M); 32.84 (NM)	Formal instrumental training, employees of music bands, minimum of 10 years of regular practice	Operation Span, Reading Span, Backward Digit Span

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Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
Jansen et al. (2022)	127 (63/64)	22.58 (M); 23.23 (NM)	Played main instrument > 9 years, > 6h/ week practice	2-back Task
Lee et al. (2007)	40 (20/20)	22	Questionnaire about MT	Backward Digit Span, Non-word Span, Operation Span
Lu and Greenwald (2016)	60 (30/30)	22.27 (M); 22.97 (NM)	M = 16.53 years of MT	Digit Span
Mandikal Vasuki et al. (2016)	35 (17/18)	28 (M), 25 (NM)	Began musical training at the age of 9 or earlier, constant musical activity	Backward Digit Span
Mansens et al. (2018)	1101 (277/824)	74.4 (M); 74.3 (NM)	M (time of music making in 2 weeks) = 280 minutes	Backward Digit Span
Meyer et al. (2020)	72 (14 experts /38 amateurs/20)	19.85 (expert); 20.79 (amateur); 19.79 (NM)	Experts: began formal MT at maximal age 10, practiced music for minimum of 10 years; amateurs: more than 1 year of MT, but not meeting experts' criteria	List Sorting WM (NIH Toolbox)
Moradzadeh et al. (2015)	153 (81/72)	22.01	M = 12 years of MT, active instrumentalists	Dual 2-back Task
Mussoi (2021)	31 (15/16)	69.5 (M); 70.1 (NM)	Start of MT by the age of 10, minimum of 5 years of formal MT, continuous MT, current practice minimum of 3 hr/week	Digit Span (WAIS)
Pallesen et al. (2010)	21 (11/10)	25 (NM); 28 (M)	Students or graduates of a music academy	2-back Task

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

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Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
Parbery-Clark et al. (2011)	37 (18/19)	55 (M), 54 (NM)	Began musical training at the age of 9 or earlier, constant musical activity	Auditory WM (AWM): Woodcock-Johnson III subtest; Visual WM (VWM): Colorado Assessment Test
Porflitt and Rosas (2020)	70 (35/35)	30.5	Musical sophistication: OMSI; M musical sophistication level = 921; NM musical sophistication level = 163; NM play no instruments	Digit Span (WAIS)
Ramachandra et al. (2012)	60 (30/30)	20 (M); 18.9 (NM)	Music practice minimum of 4 hours/week, began formal MT before age 10	Backward Digit Span, Reading Span
Sabir (2011)	40 (20/20)	35.2 (M); 33.2 (NM)	M = 20.4 years of MT	Digit Span
Schulze et al. (2012)	40 (20/20)	19.6 (NM); 25.4 (M)	Local orchestra, music conservatory, mean duration of MT 17.65 years	Tonal WM task for tone sequences
Strait et al. (2010)	33 (18/15)	18-40	MT start at < 9 years, continuous practice for > 10 years	Backward Digit Span
Strong and Mast (2019)	58 (23 high-activity/22 low-activity/13)	71.3 (high-activity), 73.9 (low-activity), 74.2 (NM)	High-activity musicians: > 10 years of private lessons, low-activity musicians: < 10 years of private lessons	Backward Digit Span
Suárez et al. (2016)	54 (24/30)	22.5 (M); 22.67 (NM)	Formal MT > 4 years	Backward Digit Span

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

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Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' mean age	Definition/Test of Music Training	WM Task
Vanden Bosch der Nederlanden et al. (2020)	60 (30/30)	21.6 (M); 20.27 (NM)	PROMS, M = 11.63 years of MT	Backward Digit Span
Weiss et al. (2014)	75 (42/33)	23.5 (M); 23.2 (NM)	M = 11.9 years of MT	Digit Span
Yeşil and Ünal (2017)	44 (22 first year/22 fourth year)	22	Comparison of first and fourth year students in classes of the music department of the university	Backward Digit Span
Yoo and Bidelman (2019)	31 (16/15)	25.4	Minimum of 8 years of continuous MT starting before age 10	Backward Digit Span
Zuk et al. (2014)	30 (15/15)	24.8	Seeking or obtained a music performance degree, working professionals	Backward Digit Span

Note. All descriptive data necessary for calculating effect sizes are available on OSF.

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

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Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

Table 4

Cognitive Flexibility Studies Included in the Meta-Analysis, Characterized by Sample Size, Participants' Mean Age (Separated for M (Musicians) and NM (Non-Musicians), if Applicable), Definition of Music Training (MT), and Cognitive Flexibility Task Used in the Respective Study

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Cognitive flexibility Task
Bialystok and DePape (2009)	95 (47/48)	23.8	Instrumentalists, vocalists (classically trained)	Trail Making B
Boebinger et al. (2015)	50 (25/25)	27.2	MT starts before age of 7, minimum of 10 years of music experience, still actively playing	Trail Making A / B
Clayton et al. (2016)	34 (17/17)	22.5 (M); 20.47 (NM)	Minimum of 10 years of formal MT, minimum practice 5 h/ week	Design Fluency
Gade and Schlemmer (2025)	71 (52/19)	age range: 18–50	MT Scale Gold MSI, minimum of 5 years of piano/organ practice	Switching task music, switching task letters
Giovagnoli and Raglio (2011)	42 (21/21)	33.2 (M); 33.4 (NM)	Professional teachers in public music schools	Trail Making A / B
Gray and Gow (2020)	60 (30/30)	69.66	M had > 10 years of MT	Trail Making B
Groussard et al. (2020)	143 (49/49/45 actors)	47.47 (NM); 47.84 (M); 41.58 (Actor)	Current and regular practice at the time of the study for more than 3 years, more than 4 h/ week, formal music training	Phonemic fluency, Semantic fluency
Hanna-Pladdy and MacKay (2011)	70 (22/21/27 low activity musicians)	69.7 (NM); 69.5 (M low-activity); 70.8 (M high-activity)	Low activity musicians: minimum of 1 year, maximal 9	Trail Making B

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Cognitive flexibility Task
			years of instrumental experience; high activity musicians: minimum of 10 years of instrumental experience and formal music training	
Hanna-Pladdy and Gajewski (2012)	70 (33/37)	68.45 (M); 68.81 (NM)	M = 37 years of MT	WCST
Hao et al. (2023)	48 (22/26)	Students (no age reported)	Major in music	Numerical Set Switching
Hou et al. (2014)	88 (44 superior pitch identification SPI: 26 early MT, 18 no MT/44 average pitch identification API: 26 early MT, 18 no MT)	20.74 (SPI, early training); 20.27 (API, early training); 20.81 (SPI, no training); 20.46 (API, no training)	SPI: > 80% correct pitch identification; API: 9.52–76.19% correct pitch identification	Trail Making A / B
Jansen et al. (2022)	127 (63/64)	22.58 (M); 23.23 (NM)	Played main instrument > 9 years, > 6h/ week practice	WCST
Mansens et al. (2018)	1101 (277/824)	74.4 (M); 74.3 (NM)	M (time of music making in 2 weeks) = 280 minutes	Letter Fluency, Word Fluency
Meyer et al. (2020)	72 (14 experts /38 amateurs/20)	19.85 (expert); 20.79 (amateur); 19.79 (NM)	Experts: began formal MT at maximal age 10, practiced music for minimum of 10 years; amateurs: more than 1 year of MT, but not meeting experts' criteria	WCST

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

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Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Cognitive flexibility Task
Moradzadeh et al. (2015)	153 (81/72)	22.01	M = 12 years of MT, active instrumentalists	Task-switching
Moser (2003)	276 (120/156)	63.5 (M); age range 57–85 (NM)	Community band musicians vs. normative population, > 15 years of playing experience	Trail Making B
Porflitt and Rosas (2020)	70 (35/35)	30.5	Musical sophistication: OMSI; M musical sophistication level = 921; NM musical sophistication level = 163; NM play no instruments	WCST
Sabir (2011)	40 (20/20)	35.2 (M); 33.2 (NM)	M = 20.4 years of MT	Trail Making B
Strong and Mast (2019)	58 (23 high-activity/22 low-activity/13)	71.3 (high-activity), 73.9 (low-activity), 74.2 (NM)	High-activity musicians: > 10 years of private lessons, low-activity musicians: < 10 years of private lessons	Trail Making A / B
Vanden Bosch der Nederlanden et al. (2020)	60 (30/30)	21.6 (M); 20.27 (NM)	PROMS, M = 11.63 years of MT	Berg's Card Sort (analog WCST)
Yamashita et al. (2022)	60 (30/30)	70.8 (M), 71.4 (NM)	MT for minimum of 20 years, still actively playing, Gold-MSI assessment	Trail Making B
Zuk et al. (2014)	30 (15/15)	24.8	Seeking or obtained a music performance degree, working professionals	Design Fluency

Note. All descriptive data necessary for calculating effect sizes are available on OSF.

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

Table 5

Inhibition Studies Included in the Meta-Analysis, Characterized by Sample Size, Participants' Mean Age (Separated for M (Musicians) and NM (Non-Musicians), if Applicable), Definition of Music Training (MT), and Inhibition Task Used in the Respective Study

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Inhibition Task
Amer et al. (2013)	42 (18/24)	60.12	Music experience M = 19.78 years	Auditory Stroop, Simon
Boebinger et al. (2015)	50 (25/25)	27.2	MT start before age of 7, minimum of 10 years of music experience, still actively playing	Stroop
Chang-Arana and Luck (2018)	29 (19/10)	27.5 (M); 27.2 (NM)	M = 19.2 years of MT	Stroop
Clayton et al. (2016)	34 (17/17)	22.5 (M); 20.47 (NM)	Minimum of 10 years of formal MT, minimum practice 5 h/week	Color Word Interference
Criscuolo et al. (2019)	101 (23/51/27 amateurs)	28.44	>5 years of music practice, final degree at a music academy or job as musician or music teacher	Stroop
D'Souza et al. (2018)	153 (81/72)	22	M = 12 years of formal MT (minimum of 8 years), beginning of training at age 7	Stroop, Flanker, Stop-Signal
Gray and Gow (2020)	60 (30/30)	69.66	M had > 10 years of MT	Stroop
Hou et al. (2014)	88 (44 superior pitch identification SPI: 26 early MT, 18 no MT/44 average pitch identification API: 26 early MT, 18 no MT)	20.74 (SPI, early training); 20.27 (API, early training); 20.81 (SPI, no training); 20.46 (API, no training)	SPI: >80% correct pitch identification; API: 9.52-76.19% correct pitch identification	Stroop, ANT, Stop-Signal
Jansen et al. (2022)	127 (63/64)	22.58 (M); 23.23 (NM)	Played main instrument > 9 years, > 6h/ week practice	Flanker

Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Inhibition Task
Mandikal Vasuki et al. (2016)	35 (17/18)	28 (M), 25 (NM)	Began musical training at the age of 9 or earlier, constant musical activity	Stroop
Meyer et al. (2020)	72 (14 experts /38 amateurs/20)	19.85 (expert); 20.79 (amateur); 19.79 (NM)	Experts: began formal MT at maximal age 10, practiced music for minimum of 10 years; amateurs: more than 1 year of MT, but not meeting experts' criteria	Flanker (NIH Toolbox)
Moreno et al. (2014)	28 (13/15)	23.6 (NM); 26.5 (M)	Amateur instrumentalist with minimum of 12 years of MT	Go/No-Go
Moussard et al. (2016)	34 (17/17)	69.2 (M); 69.9 (NM)	Advanced musical experience; mean number of years of active music experience 57.2 years	Go/No-Go
Porflitt and Rosas (2020)	70 (35/35)	30.5	Musical sophistication: OMSI; M musical sophistication level = 921; NM musical sophistication level = 163; NM play no instruments	Stroop; Go/No-Go
Sabir (2011)	40 (20/20)	35.2 (M); 33.2 (NM)	M = 20.4 years of MT	Stroop, FAS
Schroeder et al. (2016)	219 (42 M/69 bilingual M/ 43 bilingual NM/ 65 NM)	21.9	M = 11.26 years of MT	Simon
Slater et al. (2017a)	60 (42/18)	23.5 (NM); 23.0 (M vocal); 24.0 (M percussion)	Continuous practice minimum of past 5 years with either percussion or vocals as primary instrument	Integrated Visual and Auditory Plus Continuous Performance Test
Slater et al. (2017b)	36 (16/20)	25.6 (M); 23.7 (NM)	Continuous practice minimum of past 5 years, percussion as primary instrument	Integrated Visual and Auditory Plus Continuous Performance Test

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Author(s), Year	Sample size (Musicians/ Non-Musicians	Participants' age	Definition/Test of Music Training	Inhibition Task
Strong and Mast (2019)	58 (23 high-activity/22 low-activity/13)	71.3 (high-activity), 73.9 (low-activity), 74.2 (NM)	High-activity musicians: > 10 years of private lessons, low-activity musicians: < 10 years of private lessons	Color Word Interference
Vanden Bosch der Nederlanden et al. (2020)	60 (30/30)	21.6 (M); 20.27 (NM)	PROMS, M = 11.63 years of MT	Stroop
Velasquez et al. (2024)	33 (no preselection)	19.2	Gold-MSI; based on their answers, participants were split at the median into high-MT and low-MT	Stroop, Simon
Yeşil and Ünal (2017)	44 (22 first-year/22 fourth-year)	22	first and fourth year students from classes of the music department of the university	Stroop
Zuk et al. (2014)	30 (15/15)	24.8	Seeking or obtained a music performance degree, working professionals	Color Word Interference

Note. All descriptive data necessary for calculating effect sizes are available on OSF.

Jahrbuch Musikpsychologie
2026, Vol. 34, Article e245
https://doi.org/10.5964/jbdgm.245

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Statistical Analyses

Descriptive statistics including mean and standard deviations for the two groups (musicians and non-musicians) were used to compute Hedges' *g*. The *metafor* package Version 4.8-0 (Viechtbauer, 2010) and R 4.5.3 were used to analyze the data. We ran random mixed effect models with study on Level 1 and task/comparison on Level 2 to account for the nested structure of some studies. With the chosen multilevel analysis design, features such as testing the same group of participants in different conditions or with different tasks (e.g., a Stroop task as well as a Simon task were assessed in the same sample as two measurements of the EF facet inhibition) are accurately represented and variance structures within and between studies are preserved and controlled for (Baayen et al., 2008; Borenstein et al., 2010; Viechtbauer, 2010). Correlative studies were screened for reported correlations between music training indexes (mostly self-reported years of instrumental training) and dependent variables measuring EFs (e.g., WM span, Stroop effects). Those correlations were transformed into Hedges' *g* to match dependent variables across analyses. For the correlational data, only facet of EF was considered as moderating variable. For the studies assessing group comparisons, we ran an overarching model that contained the three facets of EFs as moderating variable (Aryanto et al., 2026). Next, given the results of significant influences of the separate facets, we ran separate meta-analyses for each of the three facets of EF. These three separate meta-analyses were run first as a basic model without moderator variables (see forest plots). In the second step, the following five categorical moderating variables were included: duration of music training (above vs. below the median training duration in this facet), age (young/old), task (frequent/other), task modality (auditory vs. visual stimulus presentation), and risk of bias (combined score of all four risk-of-bias variables, see coding protocol on OSF and Table S2). The five moderators were coded as categorical even when the original studies had used continuous measures (age, duration of training), since the resulting age and training duration distributions in many group comparison studies did not follow a normal distribution but were bimodal.

Results

Our final sample for the meta-analysis included 72 studies published between 2003 and 2025. Descriptive statistics of all studies included in the meta-analyses, including information on moderating variables and risk of bias variables, can be found on OSF.

Correlational Studies and Overarching EF Model

In our first analysis, we considered the correlational studies. In those 16 studies and 48 reported coefficients, we found that model fit was roughly the same when adding facet (WM, cognitive flexibility, inhibition) as a moderator as when not doing so. Fit

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indices of the model including facet as a moderator had marginally larger values in the two commonly used fit criteria (Akaike information criterion AIC -65.59 with vs. -73.85 without moderator, Bayesian information criterion BIC -58.36 with vs. -70.15 without moderator). For better comparability to other meta-analyses (Aryanto et al., 2026) and for theoretical reasons we decided to report the model with moderator (Kadane & Lazar, 2004). When considering the moderator, heterogeneity was reduced, yet still significant ($Q(45) = 64.30$, $p = .031$ vs. $Q(47) = 66.28$, $p = .033$). Overall, a relation of $g = 0.16$ was observed (95% CI [0.11; 0.21], $z = 6.29$, $p < .001$, see Figure 2).

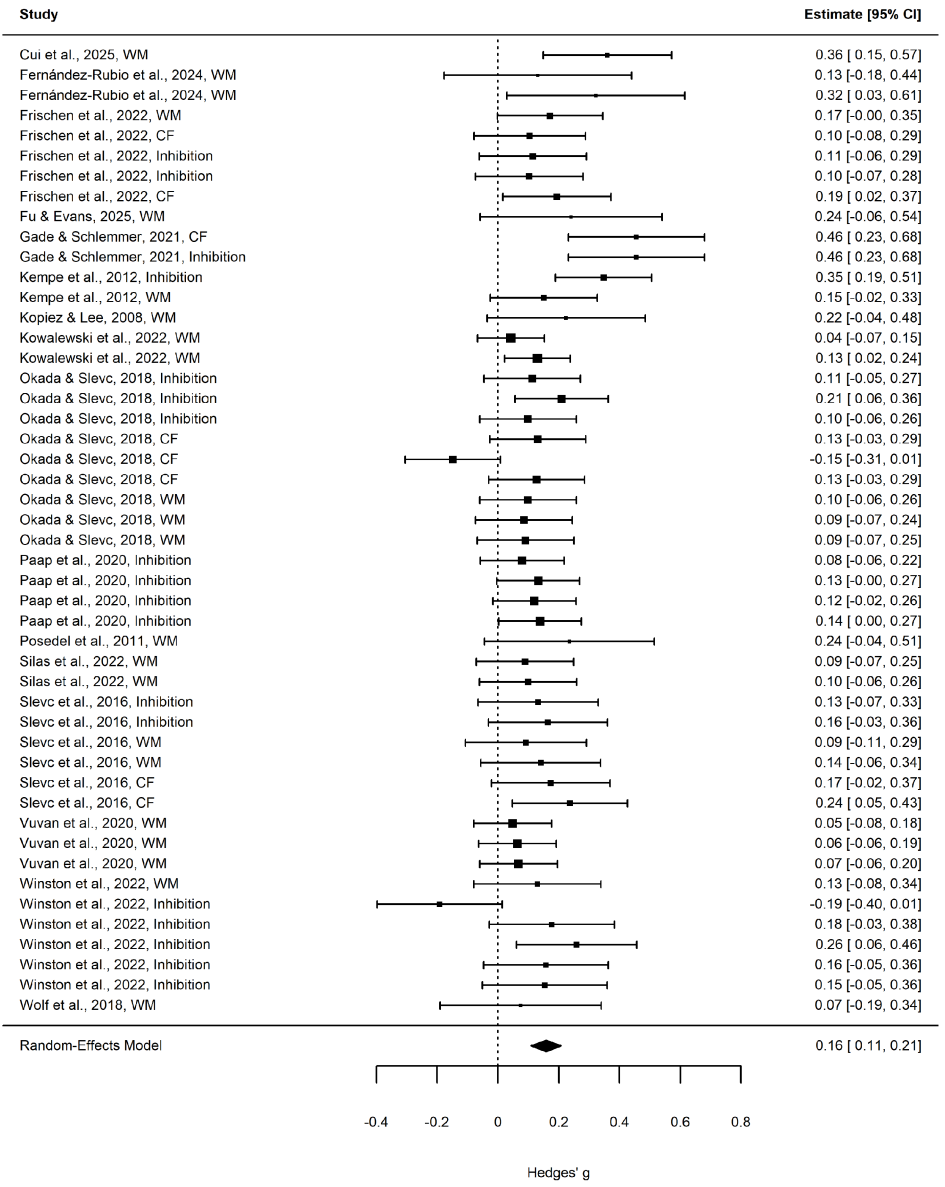
We observed significant effects of the relationship between music training and EF performance for studies assessing cognitive flexibility ($n_{data} = 8$, $g = 0.16$, $z = 3.71$, $p < .001$), for studies assessing inhibition ($n_{data} = 18$, $g = 0.17$, $z = 4.11$, $p < .001$), and for studies assessing WM ($n_{data} = 22$, $g = 0.15$, $z = 4.06$, $p < .001$).

The second meta-analysis included all group comparison studies and considered facet of EF as moderator, as in the previous analysis. Here, the model with facet as moderator provided better fit to the data as indexed by AIC (331.79 with vs. 344.93 without moderator) and BIC (343.29 with vs. 350.71 without moderator) and is therefore reported. In this model, heterogeneity across samples was high ($Q(131) = 750.96$, $p < .001$) as was the heterogeneity within the moderator ($Q(3) = 50.08$, $p < .001$). Overall, an effect in favor of musically trained groups was observed when no moderator was considered ($g = 0.59$, 95% CI [0.38; 0.80], $z = 5.62$, $p < .001$). When facet was considered as moderator, the effect was smallest yet still significant for studies investigating inhibition ($g = 0.43$, 95% CI [0.20; 0.66], $z = 3.71$, $p < .001$). Studies assessing cognitive flexibility showed a slightly larger effect size ($g = 0.51$, 95% CI [0.29; 0.74], $z = 4.50$, $p < .001$). The largest effects were reported in studies assessing WM ($g = 0.69$, 95% CI [0.48; 0.89], $z = 6.40$, $p < .001$). Overall, the analyses reported so far support the decision to analyze each component separately in more detail, i.e., concerning further moderating variables.

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Figure 2

Forest Plot That Displays the Included Correlations (Hedges' g) Between Music Training and EFs for All Correlational Studies (n = 16)



Note. Data indexed by authors and year from the overall data file for correlational studies can be found on OSF. The size of each individual square reflects the standard error of the respective effect size.

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Working Memory

In the meta-analysis for WM based on 45 studies including 70 nested comparisons of musicians to non-musicians, we found an overall heterogeneous sample ($Q(69) = 436.17$, $p < .001$, see Figure 3). Despite this heterogeneity, we found an overall effect of $g = 0.63$, 95% CI [0.39; 0.87], $z = 5.13$, $p < .001$, in favor of the musician group suggesting better WM performance overall in those participants who underwent music training. One study yielded particularly large effect sizes relying on d' in a backward recognition task for tonal WM with a two-choice response setting (Schulze et al., 2012). When excluding this study, the overall effect of $g = 0.50$, 95% CI [0.37; 0.63], $z = 7.39$, $p < .001$ in favor of the musician group remained with reduced heterogeneity ($Q(65) = 226.79$, $p < .001$).

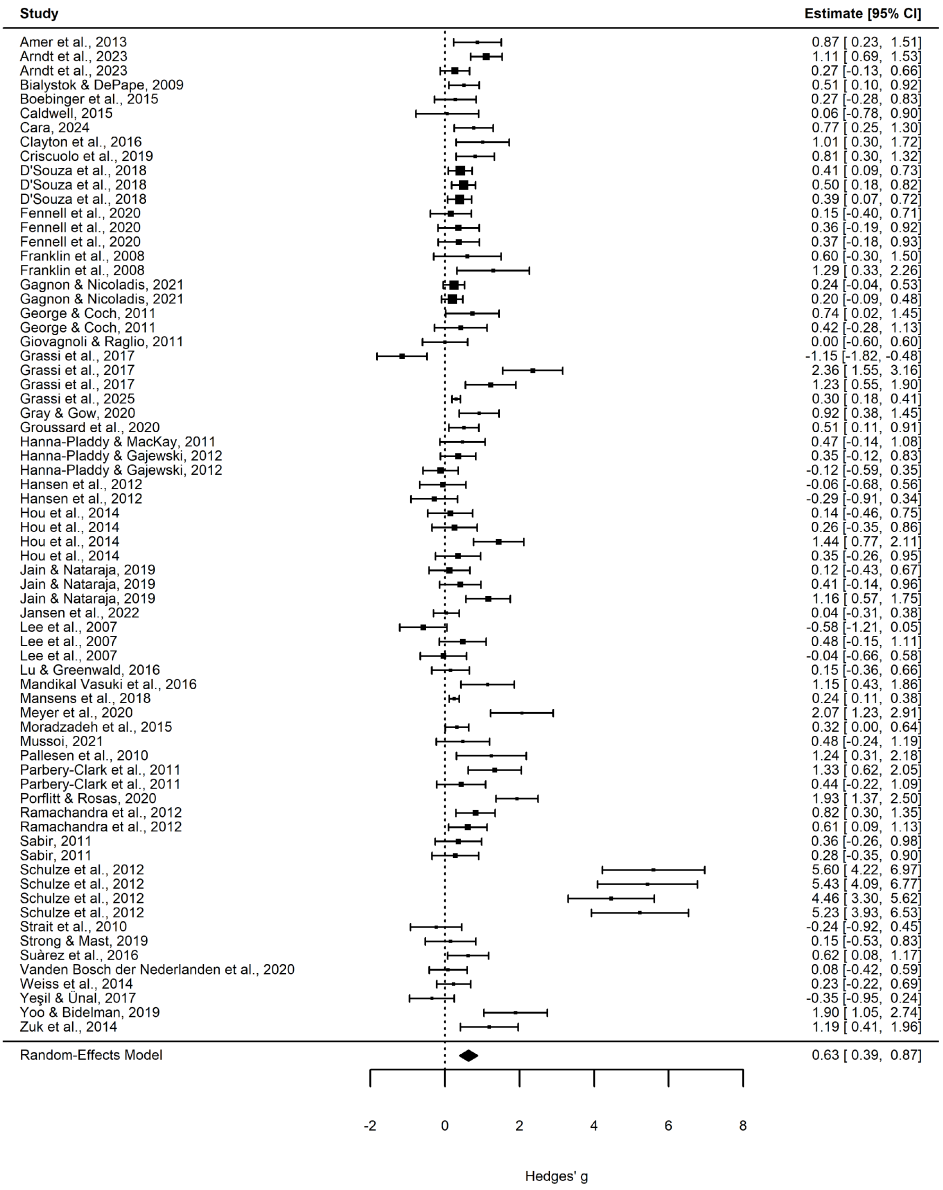
When testing for influences of moderating variables or risk of bias, we found that task modality significantly reduced the effect in favor of musicians when only visual tasks were used compared to auditory tasks ($z = 7.08$, $p < .001$). When both modalities (visual and auditory) were used in the tasks, a significant but smaller reduction in effect size (i.e., smaller benefits of the musician group) due to this moderator emerged ($z = 2.07$, $p = .039$). Risk of bias score, task type, age, and duration of music training had no significant moderating influence.

To test for publication bias, we computed Kendall's *tau* as correlation between outcome and sample size. A significant correlation would indicate a publication bias (as the default assumption is no relation between sample size and effect and it is presumed that significant effects are more likely to be published). We observed a significant correlation (Kendall's $tau = .34$, $p < .001$) being suggestive of a publication bias that was further confirmed by the regression test for funnel plot asymmetry ($z = 7.78$, $p < .001$).

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Figure 3

Forest Plot That Displays the Included Comparisons and Effect Sizes (Hedges' g) With CIs for All WM Studies



Note. Data indexed by authors and year from the overall data file for group comparison studies of WM can be found on OSF. The size of each individual square reflects the standard error of the respective effect size.

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Cognitive Flexibility

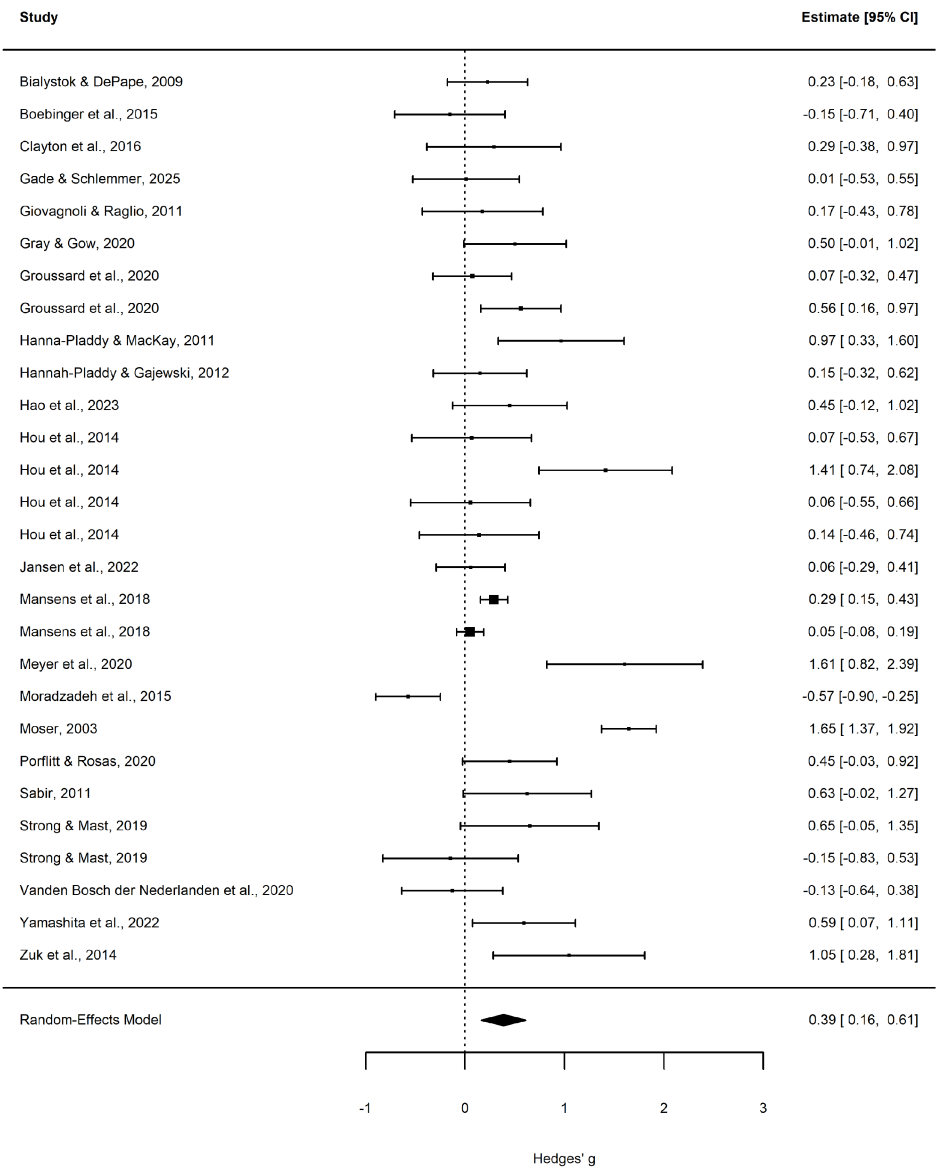
For studies assessing cognitive flexibility (N = 22) we identified 28 comparisons between musicians and non-musicians that tested for differences in cognitive flexibility measures. Heterogeneity was large as for WM ($Q(27) = 181.57$, $p < .001$). Overall, we found an effect of $g = 0.39$, 95% CI [0.16; 0.61], $z = 3.41$, $p < .001$, again in favor of the musician group. Figure 4 gives an overview of the studies included.

When testing for the same moderators as in the analysis of WM, we found that task influenced the results significantly ($z = 3.80$, $p < .001$). Studies using the Trail Making Test Part B found more evidence in favor of musicians than other tasks. Furthermore, a higher risk of bias score was associated with a significant reduction in estimated overall effect size ($z = -3.29$, $p = .001$). All other moderators failed to exert significant influence on the overall estimated effect size. Again, we found an indication of publication bias by testing for correlation (Kendall's $tau = .31$, $p = .02$) but no asymmetry in the funnel plot ($z = 1.26$, $p = .21$) in the data collected for the EF facet cognitive flexibility.

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Figure 4

Forest Plot That Displays the Included Comparisons and Effect Sizes (Hedges' g) With CIs for All Cognitive Flexibility Studies



Note. Data indexed by authors and year from the overall data file for group comparison studies of cognitive flexibility can be found on OSF. The size of each individual square reflects the standard error of the respective effect size.

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Inhibition

For the last facet of the classical (Diamond, 2013; Miyake et al., 2000) EF taxonomy, inhibition, we included 36 comparisons extracted from 23 studies. As for WM and cognitive flexibility, heterogeneity among effect sizes was large ($Q(35) = 123.23$, $p < .001$). Nonetheless and consistent with results from WM and cognitive flexibility we observed an overall effect of $g = 0.47$, 95% CI [0.25; 0.68], $z = 4.26$, $p < .001$ in favor of the musician group. Figure 5 gives an overview of the included studies and effect sizes.

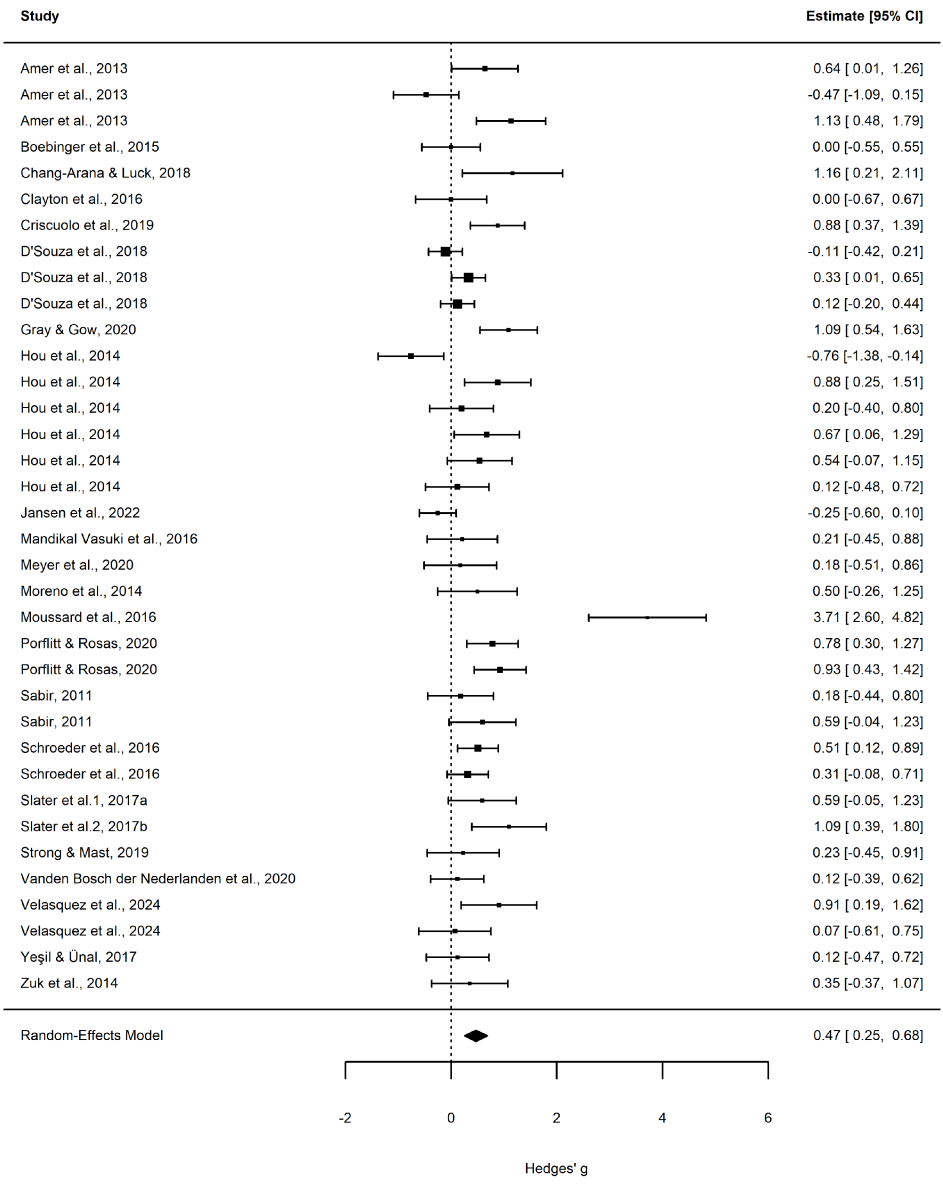
In the analysis of potential moderators, task modality acted as a significant moderator and reduced the effect size in favor of musicians significantly ($z = -2.14$, $p = .032$) when tasks with visual stimulus material were used. Next, a higher risk of bias score went along with a reduction in effect size ($z = -2.26$, $p = .023$). No other moderator influenced effect size estimates to a significant degree. When testing for publication bias, the correlational analysis (Kendall's *tau* = .20, $p = .078$) did not provide evidence for publication bias, while the test on funnel plot asymmetry ($z = 3.28$, $p = .001$) provided evidence for publication bias.

Table 6 gives an overview of the influence of moderators in the three reported meta-analyses on the EF facets WM, cognitive flexibility, and inhibition.

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Figure 5

Forest Plot That Displays the Included Comparisons and Effect Sizes (Hedges' g) With CIs for All Inhibition Studies



Note. Data indexed by authors and year from the overall data file for group comparison studies of inhibition can be found on OSF. The size of each individual square reflects the standard error of the respective effect size.

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Table 6

Moderators Assessed and Their Influences on Effect Sizes in the Three Reported Meta-Analyses on Group Differences for the EF Facets WM, Cognitive Flexibility, and Inhibition

	EF facet		
Moderator	**Cognitive flexibility**	**Inhibition**	**WM**
Age (old vs. young)	no effect	no effect	no effect
Music training (above vs. below median split)	no effect	no effect	no effect
Task modality (auditory vs. visual)	no effect	smaller effect sizes for tasks presented in the visual modality	smaller effect sizes for tasks presented in the visual modality or in both modalities
Task Type (frequent vs. other)	smaller effect sizes for the less frequently used task	no effect	no effect
Risk of bias (sum score)	smaller effect sizes for samples with higher risk of bias	smaller effect sizes for samples with higher risk of bias	no effect

Discussion

The aim of our study was to identify the magnitude of any relationships between music training and EFs by summarizing existing studies in a meta-analysis. In our meta-analysis we opted for a more detailed picture of associations between music training and EFs in adults by considering both the shared variance of the construct as well as the classic tripartite structure of EFs, namely WM, cognitive flexibility, and inhibition (Diamond, 2013; Miyake et al., 2000). For all facets we identified comparisons between different groups of participants that received music training and those who did not or to a much lesser degree. Additionally, we analyzed studies assessing music training as continuous variable and covariate for performance in EFs. Besides calculating mean effects for the respective group differences and correlations, we considered the mean age, the duration of music training, the modality of the cognitive task, the type of cognitive task, and a risk of bias score as potential moderating variables in our analyses.

The analysis across all three facets of EFs revealed a significant mean effect for both the group comparisons (g = 0.59) and the correlational studies (g = 0.16). The group effect is larger than the findings by Pérez-Eizaguirre et al. (2023, g = 0.37) and Aryanto et al. (2026, g = 0.43), while there is no respective result for correlational studies in

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prior work. A possible explanation for the smaller effect size in the correlational studies might be that those samples mostly reflect university populations and were less selective regarding musical training. The results of the separate meta-analyses per facet confirm the positive associations between music training and all three facets of EFs. At the same time, the effect sizes of the group comparison studies differ between the three EF facets and were highest in the studies testing for WM. WM is also the most widely researched EF facet. The overall estimated effect size for WM studies of $g = 0.50$ (without the study by Schulze et al., 2012) is of a similar magnitude as findings by Talamini et al. (2017, $g = 0.56$) and by Aryanto et al. (2026, $g = 0.49$), while our estimated effect sizes for inhibition and for cognitive flexibility are larger than those found by Aryanto et al. (2026). The reason for this difference could be due to the larger number of included studies in our analyses ($n = 72$ vs. $n = 47$). Nevertheless, it must be noted that the results of our meta-analyses are in line with all other reported meta-analyses in reporting a positive association between music training and EFs. This association can be explained by the demands of music-making as a complex activity: Firstly, music-making places high demands on WM, as it involves, for example, maintaining auditory information to assess one's own playing in relation to the desired sounds, while at the same time coordinating the execution of playing movements. Also, the representation of music in long-term memory is updated in WM to make it available for the actual performance. Secondly, cognitive flexibility is required as musicians need to adapt to changing musical parameters such as key or time signature while simultaneously performing multiple tasks such as listening, remembering, reading music, and translating musical ideas into movement. Thirdly, inhibition is required, for example, by the fact that music is most likely not performed in isolation but in close relationship to other musicians some of which require different melodic, rhythmic and temporal structure to be performed at the same time. Thus, to perform music together with other musicians, it is necessary to focus closely on one's own performance while remaining relaxed and (to a certain degree) uninfluenced by the input of others. This has some similarities with engaging in a Stroop task in which the semantic meaning of the color word must be ignored to successfully name the ink color.

The analyses of moderating variables revealed no effects of age for any facet of EFs. This means that samples with older adults resulted in similar group differences between musically trained and untrained groups as samples with younger adults or students, a finding that makes sense as all samples included healthy participants whose intensive music training had taken place during childhood or adolescence. The result suggests that the association between music training and EF is long-lasting and, if explained as a transfer effect (Jaeggi et al., 2011), does not "wear off" with age. There was also no effect of the duration of music training as moderating variable. If the relationship between music training and EFs was explained by a transfer effect (Jaeggi et al., 2011), the expectation would be larger effects in groups with longer music training. Our data do

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not support this assumption, but we would like to point out that the assessment of music training is limited to self-reported years of practice in many studies and thus not very precise (see below for a discussion of the risk of bias variables). The third moderator, task modality, affected the effect sizes for inhibition and WM; both were larger in samples with tasks using auditory stimuli than with visual stimulus material. For WM, this mirrors the result of Talamini et al. (2017) and could be interpreted as a larger near transfer effect (from music training to auditory WM) and smaller far transfer effect (from music training to visual WM). Task type was identified as a significant moderator for group comparisons in cognitive flexibility, the effects were larger in the studies employing frequently used tasks. Those tasks often yield effects in the expected direction and are therefore considered to be the "Gold Standard" for one function (Miyake et al., 2000) and frequently included in custom made batteries for cognitive assessment.

The risk of bias assessment showed that there is a substantial risk of bias in the assessment of music training in many studies. In the cross-sectional studies used in our meta-analysis, music training is most often self-reported in years of music instruction or years of instrumental activity while practice intensity (e.g., a weekly amount of practice hours) is rarely reported. This results in a lack of clarity in the operationalization of music training. Although the cut-offs used to differentiate between musicians and non-musicians are comparable in many studies, they also seem arbitrary given the lack of information on correlations between training intensity and effects. Only a minority of studies used standardized tests or professional musicians in the musically trained group. In contrast, the risk of bias was low throughout all studies for the cognitive assessment which was mostly done by standard procedures of cognitive psychology. While the sampling of participant groups is well documented in most studies, a minority of studies included potential confounding variables into their analyses. Consequently, studies differed in their overall risk of bias scores, while at the same time, this resulted in a significant moderating influence in the meta-analyses of inhibition and cognitive flexibility which had also been identified by Aryanto et al. (2026) for inhibition.

While we argue that music making has some obvious similarities with tasks used to measure EFs, we also point out that our meta-analysis cannot draw any conclusions about causal relationships. Given the use of only cross-sectional samples and correlational data, the meta-analysis is not suited to properly answer the question whether music training supports EFs or whether those with excellent EFs master music training most successfully. This question can only be answered in controlled experimental studies. Furthermore, the relationship between taking up music training, succeeding in music making, and cognitive capabilities is not controlled for in the cross-sectional and correlational studies reported. Possibly, persons with high cognitive capabilities might be more inclined to engage in further cognitively stimulating training such as music whereas those struggling with academic tasks might be more likely to drop out earlier in training before achieving a certain level (Valian, 2015). This explanation mirrors the "pre-existing

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dispositions hypothesis" (Silas et al., 2022) meaning that a disposition as a third variable could be the underlying factor influencing both cognitive and music tasks. Consequently, the result of our meta-analysis confirms a group difference between individuals with and without music training but leaves open the question of causality.

We would like to mention some further caveats. The first is that most included data came from published studies, and the analyses showed some indication of publication bias. In sum, there is the risk of publication bias while usually peer-reviewed studies should provide higher quality than unpublished work which is more likely to remain hidden in local university repositories. Additionally, not all studies provided the necessary raw data, and some requests were not answered, which is a common problem for meta-analyses. Next, different criteria (i.e., questionnaire scores, self-report) were used to quantify music training and sort participants into the musician vs. non-musician group. The effect sizes obtained for correlational studies suggest that more fine-grained measures (i.e., continuous scales) would lead to smaller yet in sum significant effects.

Overall, cross-sectional studies with adult participants who were either musically trained or not showed moderate positive associations between music training and EFs, which is especially true for the facet WM, and to a slightly lesser degree for inhibition and cognitive flexibility. Tasks assessed mostly represented well-established standard tasks for those constructs, and effect sizes were smaller yet still positive when continuous measures for music training were used, proving a robust association between music training and EFs.

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Author Contributions: Kathrin Schlemmer—Conceptualization | Data Acquisition | Writing – original draft, review & editing. Miriam Gade—Conceptualization | Data Acquisition | Statistical analysis | Visualization | Writing – original draft, review & editing. The two authors are professors at different universities, and there is no relationship of dependence or supervision.

Ethics Statement: The study was carried out in accordance with relevant institutional and national guidelines and regulations (Föderation Deutscher Psychologenvereinigungen, 2022) and with the principles outlined in the Declaration of Helsinki. Formal approval of the study by the ethics committee of the Catholic University of Eichstätt-Ingolstadt was not mandatory, as the study adhered to all required regulations. Specifically, no empirical data were collected in this study; rather, existing data were reanalyzed.

Data Availability: The descriptive data necessary for calculating effect sizes for the meta-analyses are available (see Schlemmer & Gade, 2025).

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Supplementary Materials

The descriptive data necessary for calculating effect sizes for the meta-analyses are available on OSF. Additionally, a description of the testing procedures used to measure executive functions is available on OSF (see Schlemmer & Gade, 2025).

Index of Supplementary Materials

Schlemmer, K., & Gade, M. (2025). *Executive functions and music training: A meta-analysis* [Data, materials]. OSF. https://osf.io/entg4

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