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The Training of Rhythm Skills and Executive Function: A Systematic Review

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Abstract

Objective: The focus of this study is on rhythm-elicited movement and its impacts on executive function. The main aim of this review was to identify previous, controlled intervention research on this topic, and to study the effectiveness of the included research interventions. We hypothesized we would find research supporting the alleged positive impact of rhythm training on cognition.

Methods: Systematic literature searches were performed in Web of Science (WoS), PubMed, Education Resources Information Center (ERIC), and APA PsycArticles and PsycInfo databases from 2000 to May 2022. The selected studies were evaluated for methodological quality using the modified Downs and Black checklist.

Results: The eligibility criteria of this review identified populations from preschool to old age and included research interventions that could be defined as "training music rhythm skills". Only studies with active control training using executive function (EF) measures, published between 2000 and 2022, peer reviewed, and written in English were included. From the initial result of a total of 15,677 identified records, 10 research reports met the eligibility criteria and were included in the final synthesis of this systematic review. The mean methodological quality score of these records was 24.7 out of 28 on the Downs and Black checklist. Five of the included studies provided statistically significant results in regard to our hypothesis.

Conclusion: During our targeted review period of 2000–2022, there is a fundamental paucity of studies aiming at testing the benefits of rhythm training on EF.

Keywords

Executive function, rhythm, Rhythm skills training

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Introduction

This systematic review was conducted to identify previous intervention research on rhythm skills training published between 2000 and 2022. The focus of this review was on human cognition and more specifically on controlled intervention research focusing on executive function in healthy, undiagnosed human populations from preschool age to late adulthood. In this review, priority was given to selecting interventions whose description and titles fit the definition of a "rhythm intervention."

Rhythmic skills and abilities are often measured and defined as one of the main components of musicality (Honing et al., 2015). The ability to perceive and produce rhythmic patterns has also been identified as a skill that develops with age (Ireland et al., 2018; Tichko et al., 2022) and even without specific targeted rhythm training (Stalinski & Schellenberg, 2012). Rhythm perception is multimodal and multisensory, and in addition to the

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cognitive level, the perception of musical rhythm also involves basic perceptual-motor processes (Fiveash et al., 2022). So how can we target and improve these musical rhythm skills? As rhythm perception is a multimodal and multisensory skill, the most effective training should be considered in terms of these parameters. In the discipline of music education, the pedagogical tradition of rhythmic intervention methods and "teaching rhythm" goes back centuries. Nowadays, all music studies begin with the training of rhythmic skills. Irrespective of the choice of instrument, these rhythmic skills are further refined as the student progresses toward professional musicianship.

Dance can be seen as either an inseparable or a very important part of music itself. Recreational dance is an action in which the dancer uses his/her body to move with the personally perceived structures, whether they are emotional, rhythmic, or melodic in the music (Fitch, 2016). Dance training is also a very enjoyable and effective way to learn rhythmic skills, and the whole-body movement used in dance has been shown to improve executive function (Bégel, Bachrach et al., 2022). In general, the effect of rhythmic stimulation on our motor system is intense, activating motor areas of the brain even when we are not moving our bodies (Grahn & Brett, 2007). We can consciously synchronize to an externally perceived rhythm, but we also often unconsciously synchronize to almost any rhythmic stimulus that surrounds us (Varga & Heck, 2017). Moving our bodies to the rhythm of music, on the other hand, gives us pleasure. Musical groove research approaches the phenomenon of embodied music and rhythm perception by investigating the motivational and rewarding effects of music's tendency to move our bodies (Janata et al., 2012; Matthews et al., 2020).

A recent comprehensive review by Snyder et al. (2024) recognizes three main definitions of musical rhythm perception and production in the literature: beat, meter, and rhythm perception. Beat (pulse) perception requires the ability to perceive at least one periodic level in the music, whereas meter perception requires more refined skills to perceive more complex sructures, at least two levels in the music being experienced. According to this review the perception of rhythm is currently being measured in the research field with perceptual judgment tasks and sensorimotor synchronization tasks (Snyder et al., 2024).

Rhythm perception has been connected with cognitive functions in earlier literature, and in the 21st century the research field is evolving rapidly. Neurodevelopmental disorders seem to relate to atypical rhythm perception (Lense et al., 2021), and the research field on the atypical rhythm perception of reading-impaired populations has grown during the last 10 years (Bégel, Dalla Bella et al., 2022; Goswami, 2022). Emerging research literature has identified the potential of rhythm interventions in pre-literacy development (Bonacina et al., 2015; Harrison et al., 2018; Lê et al., 2020), and the diagnostic potential of assessed rhythm abilities regarding literacy development has been acknowledged, e.g., by Bégel, Dalla Bella et al. (2022), Lundetræ and Thomson (2018) and Ozernov-Palchik et al. (2018).

In more general music science research, a substantial number of studies have been conducted on the effects of "musical activities" on cognition. The transfer effects of music training on executive function have been investigated and supported with children, e.g., by Frischen et al. (2019), Bowmer et al. (2018), and Bugos and DeMarie (2017). The embodied, motor dimension of rhythm (e.g., Grahn & Brett, 2007) is essential to this review, as the link between motor and cognitive functions has also been widely discussed and supported in previous literature (with children, e.g., Michel et al., 2019 and Vazou et al., 2020). As the link between music training and cognition has been a focus of research for decades, interesting theories and considerations have emerged. Recently, for example, Frischen et al. (2022) suggested that the theory of the basic motor learning principle and the basic human brain learning principle of *predictive processing* could also be used as a bridging element between rhythm processing and cognitive abilities.

The scientific consensus seems to be that there is positive transfer, or direct effects of music in differing areas of human cognition. However, the diversity of the nature of music activities and of music itself reflects the complexity of the field: the evidence for potential beneficial effects of music interventions is still scattered. Understanding the nature of music training and its transfer effects has been discussed in the literature (see for example Bigand and Tillmann (2022) in response to a meta-analysis by Sala and Gobet (2020)). One of the challenges of the research field may be related to interdisciplinarity. Research traditions, concepts, and even reporting conventions differ between disciplines studying the same topic, the impact of music interventions on cognition. Even traditions of drawing conclusions from data seem to differ between disciplines, as shown in a review by Schellenberg (2020), who gives examples of the differences between neuroscience and psychology research fields. The diversity of country-specific evaluation methods may also be a challenge. For example, a meta-analysis by Gordon et al. (2015) showed the diversity of measures used to evaluate literacy skills with studies focusing on the effects of music education on literacy.

To address the challenge of scattered and varied interpretations of results, to avoid the potentially inconsistent diversity of cognitive assessment in the literature, and to meet the requirement for practical impact of this review, it was decided that the main outcome measure of this review would be measures of executive function (EF). Executive function is an umbrella term used to describe a set of functions that relate to controlling and managing other cognitive processes. The developmental trajectory of executive function is long, and they are critical for learning and behavior in general (Goswami, 2019; Spreen & Strauss, 1998). It has been suggested that the three core EFs are working memory, inhibition, and cognitive flexibility (Diamond, 2013). These functions can be measured by various standardized tests, and their assessment procedures are well established (e.g., Anderson, 2002; Chan et al., 2008; Spreen & Strauss, 1998). EF abilities have for example been shown to predict academic readiness and predict literacy and math skills throughout all school grades (Zuk et al., 2014). We assumed that this choice of well-standardized and established outcome measures would be beneficial for our review. EF measures were also chosen to have a high likelihood of being replicable and to meet the standards for practicality of our research. As these measures are the standardized tests used, for example, in schools, the transfer to easily accessible information for education professionals is direct.

We defined the search criteria to include only peer-reviewed articles conducted during this millennium, written in English, and the population was defined as healthy individuals from preschool age to old age. The main aim was to study the effectiveness of rhythm intervention. We hypothesized that despite the presumptively marginal and scattered research in the field we would find studies that support the alleged impact of rhythm skills training on executive function.

Methods

This systematic review was conducted according to PRISMA guidelines (Moher et al., 2009).

Search Strategy

Literature search was conducted in PubMed (until 15 December 2021), Web of Science, Education Resources Information Center (ERIC) and APA PsycArticles and PsycInfo databases (until 18 May 2022). In all databases, search terms and combinations of terms were entered as free text in the search term field. The word combinations used were: musical rhythm; body; executive functions / musical rhythm; body; working memory / musical rhythm; body; attention / musical rhythm; body; inhibitory control / musical rhythm; body; cognition / musical rhythm; cognition / rhythm; body; executive functions / rhythm; body; working memory / rhythm; body; cognition / rhythm; body; inhibitory control / rhythm; body; attention / dance; musical rhythm; executive functions / dance; music; cognition / dance; music; executive functions / dance; executive functions / musical rhythm; executive functions.

Eligibility Criteria

Eligible studies were included if they met all the following criteria (PICOTS):

1. The population was defined as humans from preschool age to adulthood.
2. The intervention included a (musical) rhythm stimulus and the training of rhythm skills.
3. The comparison was limited to those studies that had an active control training in their research setting.
4. The outcomes were executive function (EF), including working memory, inhibition, and attention, evaluated with cognitive/neuropsychological tests.
5. The publication period was between 2000 and 2022.
6. The study type was a longitudinal research setting reported with peer-reviewed original research articles written in English.

Data Extraction

Data were extracted from WoS (Web of Science), PubMed, ERIC (Education Resources Information Center), PsycArticles, and PsycInfo databases. Possible search filters or restrictions, if available in the electronic database, were based on the pre-defined eligibility criteria (PICOTS). These search filters could be, for example, pre-defined restrictions on the age of the participants or the year of publication. No automated tools were used in this process. The data search procedure was identical in all databases, as the eligibility criteria did not differ between databases. After the initial comprehensive review of the identified records, the data were reduced by the first author by reading the abstracts and including or excluding the records based on the pre-defined PICOTS. Once the abstracts had been assessed and the duplicates removed, the formal screening of the articles was carried out by two researchers. At this point, the review continued in collaboration with the lead and senior author as a double-blind screening process, which reduced the number of records matching the eligibility criteria to a final number of 30 articles. These articles were then assessed for full-text review. See the flowchart (Figure 1) for the full review process. The full-text review was conducted manually using electronic articles retrieved in the review process. The full-text review with a more detailed and thorough examination of the studies resulted in further experimental designs being excluded from the originally identified records. The review was blind until the full evaluation of the articles was carried out. At this point, the data were considered and assessed collaboratively according to the eligibility criteria of the review. This collaboration was important as this work is highly interdisciplinary, and the expertise of both reviewers (brain research/psychology and cognitive music science/music education) was crucial for the quality of this review work. The individual expertise of both researchers (lead and senior author), for example, with EF measures, clinical diagnoses of memory impairment, music / dance education, music and movement interventions and music method terminology were fully utilized.

Study Quality Assessment

The methodological quality of the identified and included research was assessed using a modified tool originally created by Downs and Black (1998) and modified by Trac et al. (2016) on behalf of the main reviewer. The

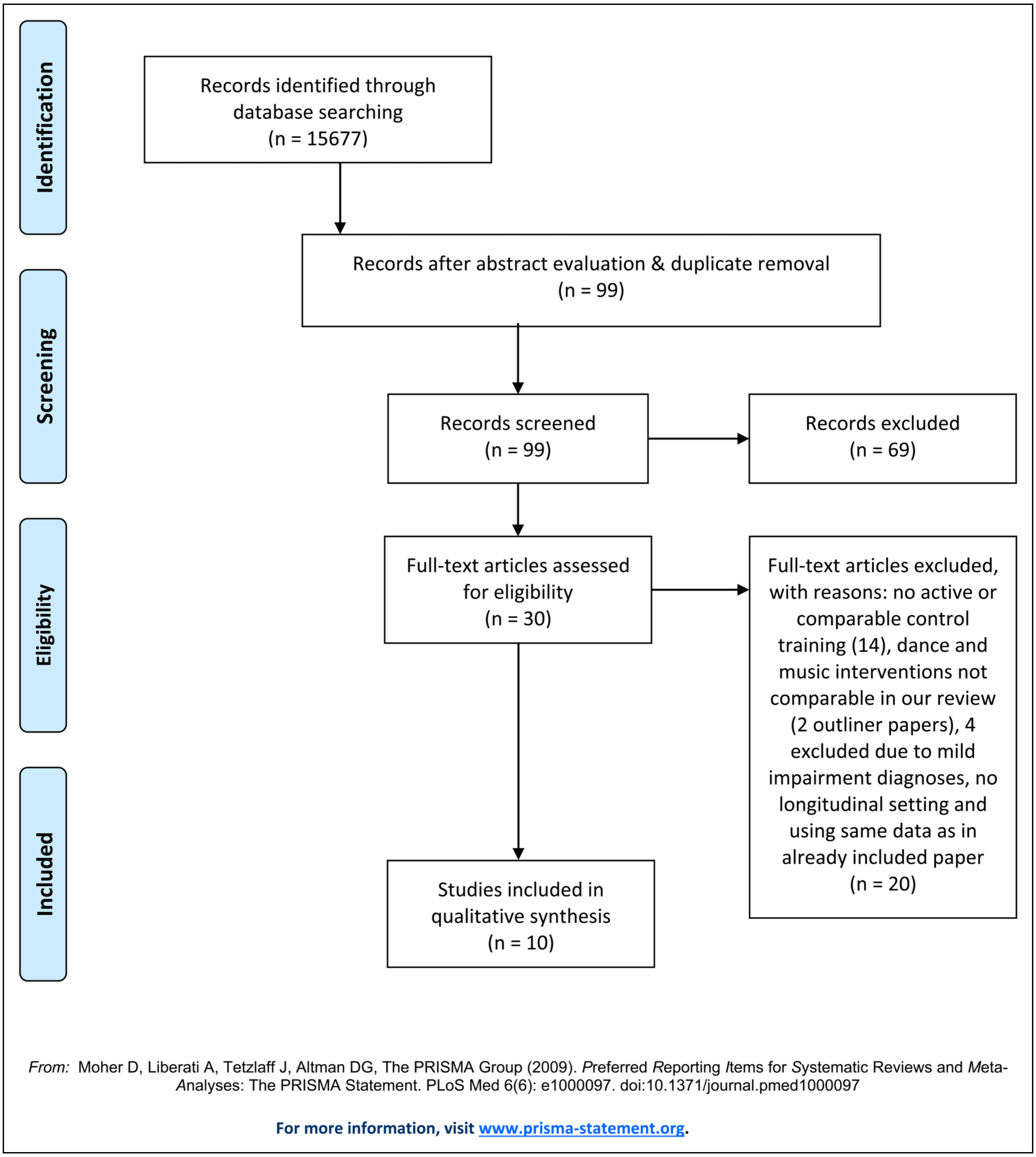

Figure 1. PRISMA 2009 flow diagram.

quality assessment checklist was originally created for the evaluation of healthcare interventions but has recently been used in systematic reviews of dance intervention research, e.g., by Meng et al. (2020). The assessment method itself consists of five domains to be assessed: quality of reporting (10 items, 11 points), external validity (three items, 3 points), internal validity with separate sections for bias (seven items, 7 points), confounding/selection bias (six items, 6 points), and statistical power (one item, 1 point).

As this instrument has not, to our knowledge, been used before in music intervention research, information on the interpretation of some of the detailed questions is included here. The questions addressed in the instrument were worded in a way that would require modification to meet the needs of different disciplines other than health care, and the modification is presented here. Question 13 (*Were the staff, places, and facilities where the patients were treated representative of the treatment received by the majority of patients?*) was adapted to our context. As the main research settings of the included studies were schools, nursing homes, or daycare centers, the assessment questions were generally adapted accordingly. Question 24 (*Was the randomized intervention allocation concealed* *from both patients and health care staff until recruitment was complete and irrevocable?*) was adapted to our context as if "patients" were either old or young cohort participants, and "health care staff" were either school or daycare center staff. This was done in all sections that benefitted from a general redefining of the research context accordingly.

The interpretation of the answers to question 4 (*Are the interventions of interest clearly described?*) is at the heart of this review: How was the intervention of interest described? Was the description clear enough for the reader to understand the main elements of the effect? Was the description clear enough for the reader to replicate the setting, the interventions of interest, or the study in general? In the quality assessment of our review, the assessment for this question was successful (1 point) if the answer to the overall question (*Are the interventions of interest clearly described? Treatments and placebo (if relevant) to be compared should be clearly described*) could be answered "yes," if the reader could distinguish the intervention in some detail (= "clear enough").

Reliability of Search Methods and Inter-Rater Agreement

The main and senior author agreed on the initial inclusion and eligibility criteria for this systematic review. The determination of the detailed search words and/or word combinations, the initial comprehensive searches, and the initial abstract assessment were carried out by the lead author alone. The screening and subsequent full-text review was conducted as a double-blind review process by the lead and senior authors. Agreement on the eligibility of the final records was reached in reflective conversations between the deciding authors. Out of the 30 research articles that were included in the full-text assessment, 11 research articles were excluded because the active control training was not active enough; the main criteria for exclusion were "not physical / active enough" (Berg et al., 2019; Bugos & DeMarie, 2017; Guo et al., 2018; Kattenstroth et al., 2013; Kim & Yoo, 2020; MacLean et al., 2014; Marquez et al., 2017; Shen et al., 2019; Shen et al., 2020; Williams & Berthelsen, 2019; Zinelabidine et al., 2022). A considerable amount of time was used to reflect on the possible inclusion or exclusion of two studies comparing "dance" and "music" training with a passive comparison (Linnavalli et al., 2018 and D'Souza & Wiseheart, 2018). As both of these active interventions are argued to include effective rhythm skill training, the decision was made to present these latter two studies as outliers in the discussion part of the report. With two studies the main author contacted the authors in question to have more detailed information about the control and main tasks, and due to "not active or comparable enough" interventions, these studies were excluded from our final data (Bowmer et al., 2018 and Kosmat & Vranic, 2017). Two studies were conducted with mild cognitive impairment populations and were excluded after a more detailed evaluation of the diagnosis of the participants was carried out (Biasutti & Mangiacotti, 2018 and Douka et al., 2019). In two studies, the research setting was ineligible according to our PICOTS, as one study compared different levels of mathematical skills of participants with the same training (Rodriguez et al., 2019), and one study only recorded immediate effects of the interventions without a longitudinal design (Kulinna et al., 2018). Finally, one study had to be excluded due to using the same data as in another already included study and not providing any new results (Eggenberger et al., 2020). Subsequently, the lead author extracted the relevant information from the final, appraised datasets, carried out the quality assessment and outlined the synthesis of the work. The accuracy of the data extraction and assessment of the studies was assessed by the senior author.

Results

Identified Records

As shown in the flowchart in Figure 1, the search procedures resulted in 15,677 identified records. Duplicate removal and initial assessment using the provided abstracts excluded 15,578 records from the original material. The remaining 99 records were then assessed in a double-blind screening process in collaboration with the lead and senior authors. Next, the final full double-blind eligibility assessment of 30 identified records was executed. This collaboration resulted in 10 eligibility criteria matching publications. For the final syntheses, the result, 10 research articles out of 15,677 identified records, were grouped according to the following: the age of the participants, the specific interventions used, the instruments used to measure executive function, the target functions these instruments were designed to measure, total time of intervention exposure, if the study was defined as preliminary research or not, and if the results were statistically significant or not. Many of these studies include other outcome measures in their research settings not highlighted in the following report. These are only reported if, for example, explanatory correlations are presented in relation to the aims and criteria of this review. Where the exact amount of training exposure was not reported by the authors, the total amount of intervention exposure was calculated using the formula of 1 month = 4.3 weeks.

Country of Research

The studies we included were conducted in Australia (Merom et al., 2016; Oppici et al., 2020), Canada (Esmail et al., 2020), Germany (Frischen et al., 2019; Hamacher et al., 2015), Hungary (Maróti et al., 2019), Israel (Zach et al., 2015), Switzerland (Eggenberger et al., 2015), Taiwan (Chuang et al., 2015), and the USA (Vazou et al., 2020).

Population

In terms of the target population, the data in selected articles was strictly divided into two main populations: the young and the old. Of the 10 research reports, five were conducted with preschool or school-aged children (4–11 years old) and five with older adult populations (65 years and over). The lack of studies on adolescent and young adult populations was evident.

Executive Function Outcome Measure

With the preschool or school-aged children the following outcome measures were utilized: Flanker Task, the Statue task (from NEPSY-II), Dimensional Change Card Sort, Matrix Span Test, Corsi Blocks, Attention Network Task (ANT) for children, Block Design, Similarity, Vocabulary and Digit Span from Wechsler Intelligence Scale IV, List sorting working memory test from NIH Toolbox, Dimensional Change Card Sort Test, The MOXO Continuous Performance Test, the Strengths and Weaknesses of ADHD-symptoms and Normal Behavior (SWAN) rating scale and the Cognitive Modifiability Battery (CMB) subtest. With the older adult populations, the utilized outcome measures were as follows: Flanker Task, Trail Making Test A & B, Executive Control Task, Paired-Associates Learning Task, Logical Memory subtest, Digit Forward and Backward Tasks from the Wechsler Memory Scale-Revised (WMS-R), Age Concentration Test A & B, Stroop Color and Word Test, Rey Auditory Verbal Learning Test, Brief Visuospatial Memory Test, Dual Task walking and counting out loud task, Dual Task with visual discrimination task, N-back, Digit Stroop, Montreal Cognitive Assessment and the Digit Symbol Substitution Task from Wechsler Adult Intelligence Scale-Revised (WAIS-R). Outcome measures are listed in Table 1.

Intervention

Out of the 10 included research reports, seven used dance as an intervention method. Dance interventions were more popular with elderly populations, as all the included elderly research reports used a dance intervention as a research method. Within the cohort of children aged 4 to 11 years, the intervention methods were more varied. Out of the five included studies in this age cohort, three studies defined the research interventions as rhythm-based training, sensorimotor entrainment-based music education with fixed rules or free movement, and a rhythmic program. The remaining two included studies defined their research intervention as dance training with different pedagogical approaches (high and low cognitive challenge) and as a dance intervention. In our final data, only two studies defined the intervention method strictly as a rhythm-based training or a rhythmic program.

Comparison

For this review we included research settings that had rhythm skills training as one of the intervention trainings and an active comparison, defined either as *another intervention training*, as in 3 studies out of the 10 by Zach et al. (2015), Frischen et al. (2019), Eggenberger et al. (2015), or as an *active control training*, as in 7 studies out of the 10 by Maróti et al. (2019), Vazou et al. (2020), Oppici et al. (2020), Chuang et al. (2015), Esmail et al. (2020), Hamacher et al. (2015) and Merom et al. (2016). The active comparison within the child cohort was executed with physical education or different forms of sport activity in four out of the five included studies. One study defined control training as a singing-based method. In all the five included elderly cohort studies, the control training for the dance intervention was light aerobic exercise or various forms of walking exercise.

Intervention Exposure

The amount of intervention exposure in our data varied from a total of 7 hr to a total of 102 hr. One study, by Zach et al. (2015), did not provide sufficient information on the overall intensity of the training to be able to calculate the exact number of minutes/hours of intervention exposure. The training was weekly in that particular study (Zach et al., 2015), and carried out twice a week in five of the studies (Eggenberger et al., 2015; Hamacher et al., 2015; Merom et al., 2016; Oppici et al., 2020; Vazou et al., 2020), three times a week in three research settings (Chuang et al., 2015; Esmail et al., 2020; Frischen et al., 2019), and four times a week in one study (Maróti et al., 2019). See Table 2 for more detailed information on the interventions.

Effectiveness

Within our data, 5 out of 10 studies did not report any statistically significant results in relation to the outcome measure (executive function measure) of our review. Of these, two studies (Chuang et al., 2015; Vazou et al., 2020) were defined as pilot or preliminary research settings. Only five studies by Frischen et al. (2019), Maróti et al. (2019), Oppici et al. (2020), Hamacher et al. (2015) and Eggenberger et al. (2015) returned statistically supportive results for our hypothesis. Four studies did not provide statistically significant results when compared with the active training (Chuang et al., 2015; Merom et al., 2016; Vazou et al., 2020; Zach et al., 2015), as all of them concluded the improvement to be highly similar in both rhythm intervention and active training groups. However, in Chuang et al. (2015) and Zach et al. (2015) there was a significant effect in both active training groups when compared with the passive control group, whereas in Merom et al. (2016) and Vazou et al. (2020), the study design did not include a third passive comparison group at all. Only one study in

Table 1. Country of implementation, study design, participant characteristics, used EF measures, and main results.

Study	Country	Study design	Participants	EF measures	Results
Zach et al. (2015)	Israel	QE	123 pre-school children, 4 to 5 years old. Dance intervention $n = 40$ Orienteering physical activities $n = 44$ Passive controls $n = 39$	MOXO Continuous Performance Test The Cognitive Modifiability Battery (CMB) subtest	Both active training (dance and specifically orienteering) improved the target executive functions.
Frischen et al. (2019)	Germany	E	76 school children, 5 to 6 years old. Rhythm-based training $n = 26$ Pitch based training $n = 27$ Sports training $n = 23$	Statue from NEPSY-II Dimensional Change Card Sort Matrix Span Test and Corsi Blocks	Significant improvement in motor inhibition within the rhythm group whereas no improvement in other groups.
Maróti et al. (2019)	Hungary	QE	63 school children, 6 to 7 years old. Sensorimotor entrainment-based music education fixed rules (*Creative Playing with Music and Movement)* $n = 22$ Free movement (*Creative Music Appreciation with Movement)* $n = 25$ Singing-based method (*Kodály method)* $n = 16$	Attention Network Task (ANT) for children, Block Design, Similarity, Vocabulary, and Digit Span from Wechsler Intelligence Scale IV	Sensorimotor entrainment-based training significantly improved working memory compared to singing-based method. Singing-based intervention improved ANT test performance significantly when compared to SE based methods.
Vazou et al. (2020)	United States of America	QE	39 children, 6 to 11 years old. Rhythmic program $n = 22$ Physical education program $n = 17$	The Strengths and Weaknesses of ADHD-symptoms and Normal Behavior (SWAN) rating scale Flanker Task	Development was similar in both PE and rhythm training groups.
Oppici et al. (2020)	Australia	RCT	80 primary school students, 8 to 10 years old. Dance training with different pedagogical high ($n = 30$) and Low ($n = 30$) cognitive challenge approaches, Standard PE curricula $n = 20$	List sorting working memory test Dimensional Change Card Sort Test Flanker Task	High cognitive load dance training had an effect on working memory performance whereas other (low cognitive and PE) groups did not, but the difference between groups was not statistically significant.
Chuang et al. (2015)	Taiwan	E	26 female participants, between 65 and 75 years old. Dance Dance Revolution – exergame $n = 7$ Brisk walking $n = 11$ Passive controls $n = 8$	Flanker Task	Both active interventions shortened reaction time with Flanker Task.
Esmail et al. (2020)	Canada	RCT	62 older adults, $M = 67.48$ years. Dance movement training $n = 23$ Aerobic exercise training $n = 21$ Passive controls $n = 18$	Dual task N-back Digit Stroop Montreal Cognitive Assessment	No statistical differences between the groups post training.
Hamacher et al. (2015)	Germany	RCT	35 older adults, 67 to 68 years old. Dance $n = 19$ Healthy exercise $n = 16$	Dual Task	Dance training improved motor-cognitive dual-task performance when compared to active control training post intervention period.
Merom et al. (2016)	Australia	RCT	115 older adults, $M = 69.5$. Ballroom dancing $n = 60$ Home based walking $n = 55$	Trail Making Test A + B Stroop Color and Word test Digit Span Backwards Rey Auditory Verbal Learning Test Brief Visuospatial Memory Test	Both groups improved; no statistically significant differences after training.
Eggenberger et al. (2015)	Switzerland	RCT	89 older adult participants (older than 70 years).	Trail making Test (TMT) A & B	Both exergame dance and combined treadmill with

(continued)

Table 1. (continued)

Study	Country	Study design	Participants	EF measures	Results
			Exergame dance $n = 30$ Combined treadmill and working memory training $n = 29$ Only treadmill $n = 30$	Executive Control Task Paired-Associates Learning Task Logical Memory subtest Digit Forward and Backward Tasks Age Concentration Tests A & B Digit Symbol Substitution Task	working memory training groups boosted executive functioning (shifting attention and working memory) when compared with simple treadmill training. When comparing the two cognitive-physical programs ("dance" and "memory"), the video game dance training had a significant effect on working memory performance.

QE = Quasi-experimental (non-randomized); E = Experimental (randomized, intact groups); RCT = Randomized controlled trial.

our data (Esmail et al., 2020) reported similar development comprehensively in each of the training groups, even in the passive control training group.

In our data, the intervention exposure of the included studies varies considerably between studies. Within the five reports that provided some significant results (Eggenberger et al., 2015; Frischen et al., 2019; Hamacher et al., 2015; Maróti et al., 2019; Oppici et al., 2020), the amount and intensity (i.e., frequency) of the intervention exposure ranged from 2 × 55 min per week for 7 weeks to 4 × 45 min per week for 34 weeks. When comparing the amount of exposure with the four reports that showed nonsignificant or null results regarding our hypothesis (Chuang et al., 2015; Esmail et al., 2020; Merom et al., 2016; Vazou et al., 2020) and provided detailed information on exposure, no clear effect related to the amount of intervention exposure can be detected.

Study Design

Out of the included data, three research settings were quasi-experimental, using non-randomized, intact intervention groups. Two out of 10 were experimental (using intact intervention groups with randomized groups), and 5 of the included studies were conducted as randomized controlled trials. As can be seen in Table 1, all the quasi-experimental (3 studies) research was conducted with child populations. For example, a child cohort study by Zach et al. (2015) had two active interventions and a passive control group comparison using pre-existing groups as they had recruited every classroom as a whole. This could be considered a standard setting in the area of educational research, representing a type of study conducted in a naturalistic school environment. Though it diminishes the internal validity and possibly increases the selection bias (Downs & Black, 1998; Trac et al., 2016), this setting, especially in this particular case with this young age group of 4- to 5-year-old children, could be considered more *ecologically valid* than a strictly randomized group.

Methodological Quality

The mean methodological quality score of these records was 24.7 out of 28 on the Downs and Black checklist. The scores for the methodological quality of the included studies were as follows. Frischen et al. (2019): 28/28, Oppici et al. (2020): 27/28, Hamacher et al. (2015): 26/28, Eggenberger et al. (2015): 26/28, Merom et al. (2016): 26/28, Esmail et al. (2020): 25/28, Vazou et al. (2020): 24/28, Maróti et al. (2019): 23/28, Zach et al. (2015): 21/28, Chuang et al. (2015): 21/28. However, the quality of the description of the interventions of training musical rhythm skills was generally poor. "Clear enough description of the intervention" did not mean "replicable" in any of the studies.

Discussion

The main objective of this systematic review was to identify previous controlled intervention research on the effects of rhythm skills training on executive function and to examine the effectiveness of the research interventions included. Although we recognized in advance that the number of records identified might be small, we hypothesized that we would find intervention research supporting the previously mentioned effects of rhythm skills training on executive function. After completing the review and synthesizing the results, the small number of identified records suggests that there is a fundamental paucity of studies in our targeted review period of 2000–2022. Our review hypothesis was only partially supported, as only 5 research articles (Eggenberger et al., 2015; Frischen et al., 2019; Hamacher et al., 2015; Maróti et al., 2019; Oppici et al., 2020) out of the 10 assessed provided results that statistically supported our hypothesis.

In our eligibility criteria we defined our intervention as a rhythm skills training intervention. After an extensive search of the databases, we concluded that it was difficult to find research reports with a detailed definition of the research intervention itself. In other words, in the entire

Table 2. The form of rhythm skills training, amount of intervention exposure, and control design.

Article	Intervention	Length in weeks	Frequency (times/week)	Session duration	Total amount of intervention exposure	Control
Zach, S., Inglis, V., Fox, O., Berger, I., & Stahl, A. (2015). The effect of physical activity on spatial perception and attention in early childhood. *Cognitive Development*, *36*, 31–39.	Dance intervention n = 40	9	1	-	-	Orienteering physical activities n = 44 Passive controls n = 39
Frischen, U., Schwarzer, G., & Degé, F. (2019). Comparing the effects of rhythm-based music training and pitch-based music training on executive functions in preschoolers. *Frontiers in Integrative Neuroscience*, *13*, 41.	Rhythm-based training n = 26	20	3	20 min	20 h	Pitch based training n = 27 Sports training n = 23
Maróti, E., Barabás, E., Deszpot, G., Farnadi, T., Norbert Nemes, L., Szirányi, B., & Honbolygó, F. (2019). Does moving to the music make you smarter? The relation of sensorimotor entrainment to cognitive, linguistic, musical, and social skills. *Psychology of Music*, *47*(5), 663–679.	Sensorimotor entrainment-based music education fixed rules (*Creative Playing with Music and Movement)* n = 22	34	4	45 min	102 h	Free movement (*Creative Music Appreciation with Movement) n = 25* Singing based method (*Kodály method) n = 16*
Vazou, S., Klesel, B., Lakes, K. D., & Smiley, A. (2020). Rhythmic physical activity intervention: exploring feasibility and effectiveness in improving motor and executive function skills in children. *Frontiers in Psychology*, *11*, 556249.	Rhythmic program n = 22	7	2	30 min	7 h	Physical education program n = 17
Oppici, L., Rudd, J. R., Buszard, T., & Spittle, S. (2020). Efficacy of a 7-week dance (RCT) PE curriculum with different teaching pedagogies and levels of cognitive challenge to improve working memory capacity and motor competence in 8–10 years old children. *Psychology of Sport and Exercise*, *50*, 101675.	Dance training with high cognitive pedagogical challenge approach n = 30	7	2	55 min	13 h	Dance training with low cognitive pedagogical challenge approach (n = 30) Standard PE curricula n = 20
Chuang, L. Y., Hung, H. Y., Huang, C. J., Chang, Y. K., & Hung, T. M. (2015). A 3-month intervention of Dance Dance Revolution improves interference control in elderly females: a preliminary investigation. *Experimental Brain Research*, *233*, 1181–1188.	Dance Dance Revolution – exergame n = 7	12	3	30 min	18 h	Brisk walking n = 11 Passive controls n = 8
Esmail, A., Vrinceanu, T., Lussier, M., Predovan, D., Berryman, N., Houle, J., … & Bherer, L. (2020). Effects of dance/movement training vs. aerobic exercise training on cognition,	Dance movement training n = 23	12	3	60 min	36 h	Aerobic exercise training n = 21 Passive controls n = 18

(continued)

Table 2. (continued)

Article	Intervention	Length in weeks	Frequency (times/week)	Session duration	Total amount of intervention exposure	Control
physical fitness and quality of life in older adults: A randomized controlled trial. *Journal of Bodywork and Movement Therapies*, *24*(1), 212–220.						
Hamacher, D., Hamacher, D., Rehfeld, K., Hökelmann, A., & Schega, L. (2015). The effect of a six-month dancing program on motor-cognitive dual-task performance in older adults. *Journal of aging and physical activity*, *23*(4), 647–652.	Dance n = 19	26	2	90 min	78 h	Healthy exercise n = 16
Merom, D., Grunseit, A., Eramudugolla, R., Jefferis, B., Mcneill, J., & Anstey, K. J. (2016). Cognitive benefits of social dancing and walking in old age: the dancing mind randomized controlled trial. *Frontiers in Aging Neuroscience*, *8*, 26	Ballroom dancing n = 60	34	2	60 min	68 h	Home-based walking n = 55
Eggenberger, P., Schumacher, V., Angst, M., Theill, N., & de Bruin, E. D. (2015). Does multicomponent physical exercise with simultaneous cognitive training boost cognitive performance in older adults? A 6-month randomized controlled trial with a 1-year follow-up. *Clinical interventions in aging*, 1335–1349.	Exergame dance n = 30	26	2	60 min	52 h	Combined treadmill and working memory training n = 29 Only treadmill n = 30

data set of our review (a total of 15,677 identified records), interventions specifically defined as "rhythm interventions" were either absent or vaguely defined. In our final data set, only two studies defined the intervention method strictly as rhythm-based training or a rhythmic program. One suggestion for the lack of research could simply be related to the traditions of music research in general. It could be argued that conventional musicological research in the 20th and 21st centuries still operate mainly within the context of the classical music tradition. And in this tradition, rhythm or movement (dance) is still seen as an ancillary element of music, and this may still be reflected in the research field in terms of the initial design of music intervention research settings and/or the reporting and interpretation of actual music interventions.

In the methods section, we addressed the challenge of defining "rhythm skills training" with two studies that were then defined as outliers in our review data. The studies by Linnavalli et al. (2018) and D'Souza and Wiseheart (2018) used dance and music training as comparison training. We concluded that these control interventions were too similar to be included in our review. When reflecting on our data, the lack of specifically rhythmic music interventions was clear. It could be argued that, according to our review, there is a lack of controlled, high-quality research on our topic, the effect of rhythm skills training on EF, for example in the fields of music education, music science and psychology. To have more room for debate and to be able to discuss the actual detailed mechanisms behind rhythm skills learning at an expert level, we decided to include dance research in our review.

As discussed in the introduction, rhythm skills as an asset that can be developed throughout human life (Ireland et al., 2018; Stalinski & Schellenberg, 2012; Tichko et al., 2022) are skills that require multimodal and embodied motor qualities (Fiveash et al., 2022), and we argue that the training of these skills should also be based on these principles. This consideration could provide tangible tools for research designs on this topic and further develop basic research specifically focused on rhythm skills training and its hypothesized effect on EF. We concluded that we could not detect a clear effect related to the amount of intervention exposure in our review data. However, when reviewing the studies that did show some significant results, we could suggest that in longitudinal research settings, training should be delivered with a total exposure of 90–120 min and at least twice a week. See Table 2 for more detailed information on the interventions.

The motivational and rewarding properties of musical activities in general, and in this case the dimension of rhythm, should be emphasized (e.g., Mas-Herrero et al., 2013). Research on groove is related to this phenomenon, as it investigates the quality we are referring to here, the ability of music to move us in a physical way (Janata et al., 2012; Matthews et al., 2020). This quality of musical activity is important in the context of this review. The majority of our included studies concluded that, especially when compared to adapted forms of physical activity, music rhythm/dance training improved executive function at least as much as, if not slightly better than, the comparative exercise training. The tendency and aim of some of the studies, especially in the elderly cohort, seems to be to promote the feasibility of dance training compared to simple physical exercise (e.g., in Chuang et al., 2015). These studies also used research measures of participants' enjoyment and motivation when comparing musical rhythm and exercise interventions (Physical Activity Enjoyment Scale, PACES, in Eggenberger et al., 2015; Health-related Quality of Life Questionnaires in Esmail et al., 2020). In the child cohort studies, Vazou et al. (2020) examined the associations between enjoyment and motivation (e.g., using the Peer Motivational Climate in Youth Sport Questionnaire) and executive function. In general, these studies concluded that dance training was either comparable to or more motivating and enjoyable than sports training. This is valuable information in terms of feasibility in both young and older age groups.

The noticeable lack of studies on this topic in adolescent and young adult populations may be a result of the chosen outcome measure (measure of executive function). Executive function develops and matures until late adolescence or even early adulthood. In older adult populations, these functions begin to slowly decline after the age of 60 (Ferguson et al., 2021). One assumption might be that these maturation and deterioration points are the sweet spots for detecting possible changes in measured functions. Perhaps this is why in our data previous research in healthy populations has focused on these age cohorts (4–11 years and 65 years and older). The outcome measures of the studies included in this review are listed in Table 1. Another explanatory factor for the lack of evidence from adolescents and young adults may be related to the choice of "rhythm skills training" as the intervention. Because we chose to include dance training, the identified records included studies of dance-based interventions, which are particularly popular in the context of elderly populations.

It could be argued that in the field of research focusing on direct or transfer effects of music/rhythm activities, the largest effect sizes have been obtained with impaired or diagnosed human populations. Neurodevelopmental disorders appear to be associated with atypical rhythm perception (Lense et al., 2021), and populations with reading disabilities appear to have atypical rhythm perception (e.g., Goswami, 2022; Ladányi et al., 2020). Larger effect sizes in impaired or diagnosed human populations may also account for the lack of research on this topic in healthy populations. All studies included in our review used study-specific hypotheses based on extensive previous research and reviews supporting the positive effects of rhythmic motor training on executive function. However, based on the results of this systematic review, it could be argued that there is a lack of research on rhythmic interventions, especially with healthy populations. In our data, 2 out of 10 studies were defined as pilot or preliminary research settings. Five of the 10 studies in our data did not report statistically significant results. One study concluded that the results were only "a trend toward a significant effect," and 4 out of 10 reported that the post-training performance of the control/comparison group was similar to that of the experimental group. Rhythm in itself is a tangible aspect that can be defined and captured from the multifaceted field of music training in general (see, for example, Ahokas et al., 2024), yet our results suggest that there is a lack of research that achieves this. In terms of our research aims, it could be argued that research in this area needs further consistency and development.

Conclusions

One of the challenges of intervention research in music, and rhythm in particular, is the lack of practical and scientific replicability. In both the practical and scientific domains, more detailed information about the intervention should be provided, either to ensure the practical implementation of the intervention, such as in educational settings, or to ensure the scientific use of the methods in replicable intervention research. Similar to many other areas of research, the principles of open science, open research, and more detailed reports with Supplementary Materials would greatly benefit the field (Ahokas, 2022; Cole et al., 2023).

Action Editor

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Peer Review

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Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

Supplemental Material

Supplemental material for this article is available online.

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