EFFECTS OF PHYSICAL EDUCATION INTERVENTIONS ON EXECUTIVE FUNCTIONS AND ACADEMIC ACHIEVEMENT IN PRIMARY SCHOOL CHILDREN: A SYSTEMATIC REVIEW

EFFETTI DEGLI INTERVENTI DI EDUCAZIONE FISICA SULLE FUNZIONI ESECUTIVE E SUL RENDIMENTO SCOLASTICO NEI BAMBINI DELLA SCUOLA PRIMARIA: UNA REVISIONE SISTEMATICA

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ABSTRACT
Recent studies confirm the contribution of physical education to the development of children's executive functions. The aim of the study is to analyze the relationship between physical activity, executive functions, and academic achievement. The PRISMA protocol was used to conduct a systematic review of SPORTDiscus and Scopus. 443 publications were selected, and 14 studies were included. The results highlight that physical education interventions at school improve executive functions, in particular memory and attention.

Recenti studi confermano il contributo dell'educazione fisica per lo sviluppo delle funzioni esecutive dei bambini. Scopo dello studio è analizzare la relazione tra attività fisica, funzioni esecutive e rendimento scolastico. È stato utilizzato il protocollo PRISMA per condurre una revisione sistematica di SPORTDiscus e Scopus. Sono state selezionate 443 pubblicazioni e sono stati inclusi 14 studi. I risultati evidenziano che gli interventi di educazione fisica a scuola migliorano le funzioni esecutive, in particolare la memoria e l'attenzione.

KEYWORDS
Physical Education; Executive Functions; Academic Achievement.
Educazione Fisica; Funzioni Esecutive; Rendimento Scolastico.

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Introduction

Recently, researchers have carried out numerous investigations to recognize the importance of physical activity on academic achievement and executive functions of children and adolescents (Yáñez Sepúlveda et al., 2016; Esteban-Cornejo et al., 2017; Pesce et al., 2019). Physical activity is one of the determinants of health in a person's life and the educational environment plays an important role in this, as shown by research. The European Commission therefore issued the Recommendations for the promotion of physical education in schools (European Commission, 2013; European Commission, 2017), stating that the school is the only institution that can guarantee all children, through curricular activities (physical education), an opportunity to meet the recommended amount of daily physical activity in developmental age (WHO, 2020). Scientific evidence confirms that physical activity improves children's executive functions, especially through collective plays, because in addition to the physiological impact of physical exercise, they require cognitive application, which implies greater activation by the brain, when games and physical exercises contain numerous situations to resolve (Martín-Martínez et al., 2015). Therefore, studying and analyzing the impact of physical education on the executive functions and academic achievement of children and adolescents can provide in-depth knowledge on the applicability of the practice to innovate educational programs (Conde & Tercedor, 2015; Khan & Hillman, 2014]. This interest has been largely motivated by the findings of cognitive function in areas of neuroscientific knowledge (Gunnell et al., 2019). The study of cognitive abilities such as attention, concentration or problem solving, among others, has a great relevance since it has been reported a close link with psychosocial development, processes of adaptation to the environment or academic achievement (Pérez et al., 2014; Schmidt et al., 2016; Schmidt et al., 2015). Some studies have investigated the design of academic curriculum. In this sense, one of the subjects that generates the greatest controversy is physical education (Cañadas et al., 2015). Although some educational policies have been aimed at reducing the number of teaching hours, the results of various studies support the importance of this subject in the integral training of students, since it favors cognitive and academic achievement (Ardoy et al., 2014); provides the necessary opportunities for the fulfilment of the premises for a healthy physical activity, which contributes to combat the high prevalence of obesity; and allows during the school day that certain brain circuits affected by the fatigue of academic tasks are replenished, enhancing cognitive functions, thereby improving academic achievement (Aguayo-Berrios et al., 2018; Domínguez-Sánchez et al., 2018).The objective of this study is to analyze scientific literature on the effects of physical education interventions on

executive functions, in order to highlight the benefits on cognitive processes and academic achievement in primary school children.

1. Methods

The systematic review methodology based on the PRISMA model was used for the review and selection of studies (Moher et al., 2009; Moher et al., 2015). The search was conducted in two phases: the first phase had the objective of identifying the studies to be included; the second phase involved the development of a matrix with the aim of identifying the studies to be subjected to further analysis. The databases consulted for the research are: SPORTDiscus and Scopus. Journal articles published in English post 01/01/2013 until the date of the last search (05/09/2023) were considered for review. The keywords used are: "executive function" OR "executive functioning" AND "academic achievement OR "academic performance" OR "academic success" AND "physical education" OR "PE". The studies were selected with reference to the following parameters: a. studies concerning primary school children; b. studies published between 2013 and 2023; c. studies investigating the effects of physical education interventions on the development of executive functions and academic performance. All search results were exported into a references manager Mendeley and duplicates were removed. An initial selection of studies was performed based on title and abstract. A more careful analysis revealed articles that met all the following inclusion criteria:

a. full text articles;
b. experimental or quasi-experimental studies;
c. studies that present a quantitative-qualitative analysis of the variables considered;
d. sample age between 6-11 years, without physical or intellectual disability.

On the other hand, the exclusion criteria are:

a. review and meta-analysis;
b. mean age range not met;
c. PA extracurricular interventions;
d. n= 21, randomized studies.

2. Results

The search strategy allowed us to find a total of 14 publications according to the criteria of established inclusion. Figure 1 shows the total number of scientific

articles searched, as well as the number of publications included in the review according to the criteria used.

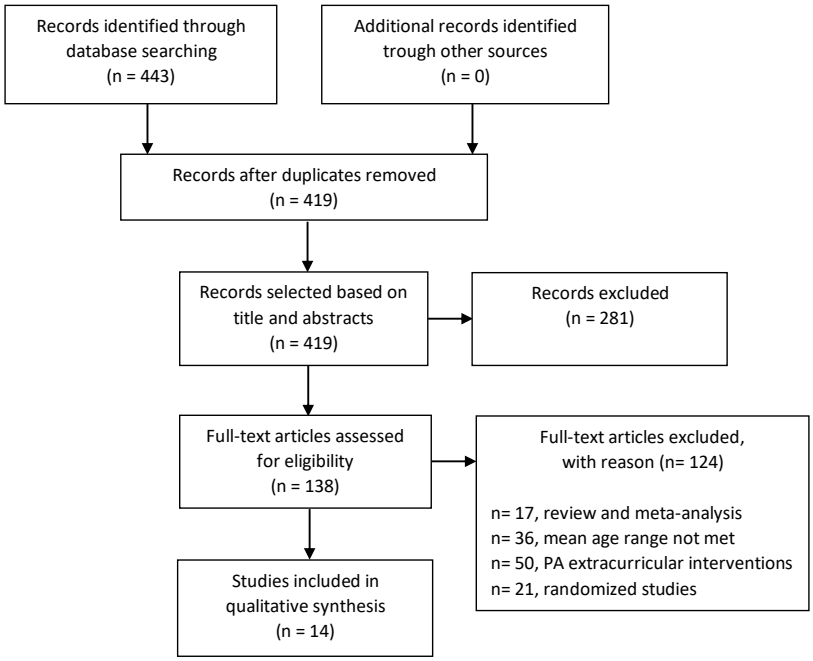

Fig. 1 PRISMA flow diagram (Moher et al., 2009) to show each stage of the systematic eligibility process.

The selected studies are experimental and cross sectional, and contribute to highlighting the importance of physical education for improving executive functions and academic achievement in primary school children. The study by Kingston et al. (2020), aimed to examine how multiple components of a school-level PA policy intervention in a primary school context affected students' EF. The PA policy had three components: Physical Education (PE), Structured Play (SP) and Unstructured Play (UP). EF tests for working memory and inhibition were conducted with a sample of 43 4th and 6th grade students before and after each component of the PA policy, once a week for four weeks, following a pilot of a week. The children's working memory was measured with a verbal visual memory test using curriculum-based vocabulary, while their inhibition was assessed through the Animal Stroop-like test. The effect of each component of the PA intervention on working memory and inhibition was analyzed with two separate repeated measures MANOVAs, controlling for gender and class as between-subject's factors. Physical education appears to be more useful for improving students' PE and it is suggested that it be

given priority in the development of PA policy in schools. Further research is warranted with longitudinal studies. The Objective of Mazzoccante's study et al. (2022), is to verify the effect of the number of physical education classes in school on anthropometric, physical, motor and cognitive indicators. This is a descriptive cross-sectional study. Three random visits were carried out on the school premises to apply the research instruments, divided into three blocks. 1) Attention cancellation test and Test of lanes A and B (collectively applied); 2) Intermittent recovery test - level 1 (Yo-Yo IR1); 3) Anamnesis, body composition and Körperkoordination für Kinder (KTK) test. The Results highlights that children who participated in two weekly Physical Education classes at school achieved lower values of body composition and greater motor domains and cognitive flexibility compared to children who attended only one weekly class. The number of physical education classes in which the child is inserted showed to influence body composition, cardiorespiratory fitness, motor coordination and cognitive flexibility. This is a descriptive cross-sectional study, which did not allow extrapolating the results in a situation of cause and effect, but it demonstrated that the number of school physical education classes offered to children can interfere with the capacity of cardiorespiratory fitness, motor coordination and cognitive flexibility and lower anthropometric indices. Kolovelonis et al. (2023), examined the effects of cognitively challenging physical activity games on students' executive functions and situational interest in physical education. Participants were 144 fourth- and fifth-grade students (75 boys, 69 girls) from four elementary schools. A four-group, repeated measures, cross-over quasi-experimental design was used in this acute experiment including a physical education session. One fourth- and one fifth-grade class from each school were randomly assigned to Group 1 with cognitively challenging physical activity games, Group 2 with a session for teaching soccer skills, Group 3 with a session for teaching track and field skills, and Group 4 (waiting-list control group) with cognitively challenging physical activity games after the post-test. Pre- and post-test measures for executive functions and a post-test measure for situational interest were included. Group 1 students, who were involved in cognitively challenging physical activity games, improved their scores in the executive functions more than students who participated in the sessions with soccer or track and field skills and waiting-list control group students. The positive effects on students' executive functions were replicated when the cognitively challenging physical activity games session was implemented in the waiting-list control group. Some improvements on executive functions for students who participated in the soccer skills session were found. Students who played the cognitively challenging physical activity games reported higher scores on novelty

compared to students in the soccer or track and field groups. These results support the effectiveness of the cognitive challenging physical activity games for triggering students' executive functions in physical education. In Zinelabidine' s study, examined the effect of an aerobic dance program as part of physical education (PE) classes on aspects of primary school children's executive functions (EFs) (inhibition, working memory, and cognitive flexibility). Participants were 41 children (21 boys and 20 girls; M age =10.30, SD = 0.50 years, M height = 134.09, SD= 3.9 cm; M weight = 35.61, SD = 7.85 kg) who were divided into an experimental group (EG) and a no-PE control group (CG). The EG followed an aerobic dance intervention as part of their PE program (45-minute sessions two days per week over eight weeks). Participants in both groups performed EF tests before and after the intervention period to evaluate their mental flexibility, inhibition, and working memory. A two-way mixed model repeated measures ANOVA revealed a significant effect of the aerobic dance program on participants' cognitive flexibility (i.e., on Trails Making Tests B-A times and committed errors) ($p < 0.001$), and on Stroop measures of inhibition (corrected number of words and corrected errors) ($p < 0.001$ and $p < 0.01$, respectively), with post-hoc analyses showing an improved achievement by the EG in working memory (digit recall score) from pre-test to post-test and in comparison to the CG ($p < 0.001$). Thus, this 8-week aerobic dance program promoted EF development among primary school children. The results of the selected studies confirm that physical education interventions improve the academic performance and executive functions of primary school children (Table 1).

Study	Authors	Sample	Methods	Results
Better movers and thinkers (BMT): An exploratory study of an innovative approach to physical education	Dalziell et al. (2015)	46 children aged between 9 and 10 years.	A 16-week intervention program using the BMT was used in which 46 children were tested on two separate occasions for coordination and balance control, academic achievement, working memory and non-verbal reasoning skills.	The development of EF has been linked to learning and academic achievement and is an essential component in the provision of EF using a new and innovative approach called 'Better Movers and Thinkers (BMT).
Acute effects of physical education, structured play, and unstructured play in children's executive functions in primary school.	Kingston et al. (2020)	43 children aged between 8 and 10 years.	The study aimed to examine how multiple components of a PA intervention in primary school affected students' EF (i.e., working memory and inhibition). The PA policy had three components: Physical Education (PE), Structured	FE appears to be more useful for improving students' PE and academic achievement and is suggested to be given priority in the development of PA policy in schools.

			Play (SP) and Unstructured Play (UP). The children's working memory was measured with a verbal visual memory test using curriculum-based vocabulary, while their inhibition was assessed through the Animal Stroop-like test.	
Moving and Academic Learning Are Not Antagonists: Acute Effects on Executive Function and Enjoyment.	Vazou et al. (2014)	35 children (10.55 ± 0.74 years)	This study investigated the acute effect of a 10-minute bout of aerobic physical activity in physical education integrated with math practice, compared to seated math practice, on executive function and enjoyment among normal-weight children (n = 24) and overweight (n = 11).	These findings suggest that integrating physical activity with academic instruction may be a realistic strategy for promoting physical activity because it may facilitate, rather than antagonize, executive function.
The effects of integrating physical activity into mathematic lessons on mathematic test performance, body mass index and short-term memory among 10-year-old children.	Fakri et al. (2020)	35 children aged between 9 and 10 years.	Physical activity was provided during mathematics class for 60 minutes per week, 2 sessions and 30 minutes per session for 7 weeks. Physical activities include jumping, running and walking. The non-physical activity group was taught via the traditional teaching method.	The percentage increase in math test score was greater in the physical activity group.
Physical Education class morphological, physical, motor and executive functions. / Clase de educación física morfológicas, físicas, motrices y función ejecutiv	Mazzoccante et al. (2022)	147 children aged between 7 and 10 years.	To apply the research tools, three random visits were carried out on the school premises, divided into three blocks. 1) Attention Cancellation Test and Lane A and B Test (collectively applied); 2) Intermittent recovery test - level 1 (Yo-Yo IR1); 3) Medical history, body composition and Körperkoordination für Kinder (KTK) test. Results: Children who participated in two weekly physical education lessons at school achieved lower body composition values and greater motor domains and cognitive flexibility compared to children who	The number of physical education lessons a child is involved in has been shown to influence body composition, cardiorespiratory fitness, motor coordination and cognitive flexibility. This is a descriptive cross-sectional study, which did not allow the results to be extrapolated into a cause-and-effect situation, but it demonstrated that the number of school physical education lessons offered to children can interfere with the ability of

			attended only one weekly lesson.	cardiorespiratory fitness, coordination motor and cognitive flexibility and lower anthropometric indices.
Motor coordination and academic performance in primary school students.	Guillamon et al. (2021)	163 children aged between 6 and 9 years.	Motor coordination was measured with the GRAMI-2 test. Academic performance was obtained through the average of the grades in the subjects of language, mathematics, natural sciences, social sciences, English and arts. The variables were calculated: motor coordination index and overall academic achievement.	The results indicate the existence of a positive relationship between motor coordination and academic achievement.
Physical activity, physical fitness, and academic achievements of primary school children.	Kliziene et al. (2018)	93 children aged between 6 and 7 years.	Flexibility test, long jump test, 3 × 10 m fast shuttle running test, 1 kg (padded) medicine ball pushed from the chest were used. Physical activity was measured using the Children's Physical Activity Questionnaire. Academic outcomes were assessed using mathematical diagnostic progress tests and mathematical learning outcomes based on curriculum content.	All 4 fitness tests had a positive linear association with physical fitness tests and mathematics test scores.
Impact of a multicomponent physical activity intervention on cognitive performance: The MOVI-KIDS study.	Sánchez-López et al. (2019)	240 children aged between 5 and 7 years.	The MOVI-KIDS program consisted of: (a) three weekly afterschool sessions of 60-min noncompetitive recreational activity during one academic year, (b) educational materials for parents and teachers, and (c) schoolyard modifications. Changes in cognition (logical reasoning, verbal factor, numerical factor, spatial factor, and general intelligence) were measured. A propensity score cross-cluster matching procedure and mediation analysis (Hayes PROCESS macro) were conducted.	This study shows that a schoolyear, multicomponent intervention consisting of a noncompetitive recreational program, parent-teacher education materials improved the cognitive abilities of first-grade children. Furthermore, our findings suggest that the effect of the intervention on cognition was mediated by changes in motor fitness.

The Effect of an 8-Week Aerobic Dance Program on Executive Function in Children.	Zinelabidina et al. (2022)	47 children aged between 9 and 11 years.	Participants were divided into an experimental group (EG) and a control group without PE (CG). EG is followed by aerobic training dance intervention as part of their physical education program (45 minute sessions two days a week over eight weeks). Participants in both groups performed EF tests before and after intervention period to assess their mental flexibility, inhibition and working memory. A two-way mixed model repeated measures ANOVA revealed a significant effect of aerobic dance program on participants' cognitive flexibility (for example, on Trails Making Tests BA times and errors made) ($p < 0.001$) and on measures of Stroop inhibition (correct number of words and correct errors) ($p < 0.001$ and $p < 0.01$, respectively), with post-hoc analyzes showing an improvement in EG performance on the task memory (digit recall score) from pre-test to post-test and compared to the CG ($p<0.001$).	This 8-week aerobic dance program promoted the development of EF among primary school children.
Acute enhancement of executive functions through cognitively challenging physical activity games in elementary physical education.	Kolovelonis et al. (2023)	144 children aged between 8 and 10 years.	A four-group, repeated-measures crossover quasi-experimental design that included a physical education session was used in this study. One fourth- and one fifth-grade class from each school were randomly assigned to Group 1 with cognitively challenging physical activity games, Group 2 with a session teaching soccer skills, and Group 3 with a session teaching soccer skills. athletics skills and to Group 4 (waiting list	The findings support the effectiveness of cognitively challenging physical activity games to activate students' executive functions in physical education.

			control group) with cognitively stimulating physical activity games after the post-test. We included pre- and post-test measures for executive functions and a post-test measure for situational interest. Students in group 1, involved in cognitively demanding physical activity games, improved their executive function scores more than students who participated in the soccer or track and field skills sessions and students in the control group on the waiting list.	
Learning "Math on the Move": Effectiveness of a Combined Numeracy and Physical Activity Program for Primary School Children.	Vetter et al. (2018)	88 children aged between 8 and 9 years.	Students were randomly assigned to physical activity (P) or class (C) groups. Group P received moderate to vigorous exercise (20 minutes, 3 times per week, 6 weeks) while simultaneously learning selected TT. Group C received similar learning, but seated. Changes in TT accuracy, overall calculation, aerobic capacity, and body mass index were assessed. Data were expressed as mean (SEM) and between condition effect sizes (ES; 95% confidence interval).	The movement combined with learning the TT was effective. Physically active learning paradigms can help meet daily physical activity guidelines by supporting or even stimulating learning.
Effects of the FITKids Randomized Controlled Trial on Executive Control and Brain Function	Hillman et al. (2014)	221 children aged between 7 and 9 years).	To evaluate the effect of a physical activity (PA) intervention on cerebral and behavioral indices of executive control in preadolescent children. Children were randomly assigned to a 9-month after-school care program or a waitlist control. In addition to changes in physical fitness (maximum oxygen consumption), electrical activity in the brain (P3-ERP) and behavioral measures (accuracy, reaction time) of executive control were collected using tasks that	The intervention improved cognitive performance and brain function during tasks requiring greater executive control. These findings demonstrate a causal effect of a PA program on executive control and provide support for PA to improve child cognition and brain health.

			modulated brain inhibition. attention and cognitive flexibility.	
Enhanced academic performance using a novel classroom physical activity intervention to increase awareness, attention and self-control: Putting embodied cognition into practice.	McClelland et al. (2014)	348 children aged between 7 and 13 years.	A proposed cognitive-based physical activity intervention, called Move4words, was developed for pupils in 10 mainstream schools in the UK.	Three controlled pilot studies have shown significant improvements in academic achievement, particularly for struggling pupils achieving in the bottom 20%.
Motor skills, attention and academic achievements - an intervention study in school year 1-.	Ericsson (2008)	251 children aged between 6 and 10 years.	The pupils were divided into two intervention groups (Groups 1 and 2) and a control group (Group 3). In the two intervention groups, physical education was extended from two to three lessons and several local sports clubs carried out physical activity for two lessons each week. Therefore the pupils in the intervention group carried out physical activities for five lessons per week and also, if necessary, one extra motor training lesson per week under the supervision of the school's physical education teacher. The control group only had mainstream school physical education for two lessons a week.	The results confirm the hypothesis that children's motor skills improve with prolonged physical activity and motor training. The pupils in the intervention groups showed improvements in attention in the 2nd school year compared to the pupils in the control group.

Tab. 2 Studies included.

Conclusions

Physical education is considered an appropriate context for the development of students' executive functions (Rudd et al., 2019). All school-age children can be involved in physical education by participating in designed educational interventions (Ennis, 2011). Therefore, physical education teachers can use cognitively demanding physical activity games to promote students' executive functions. Physical education teachers should adapt the complexity and difficulty of these games to provide students with optimal conditions to improve their executive functions. Furthermore, they should select those games that fit the objectives of the programs they implement in each class of students. Considering

that executive functions must be continually challenged to promote improvements (Diamond & Lee, 2011), physical education teachers should create appropriate learning environments, providing students with a variety of stimulating activities which vary in the degree of difficulty and cognitive involvement (Tomporowski & Pesce, 2019). For example, teaching approaches such as the divergent discovery style (Mosston & Ashworth, 2008) may be considered appropriate. Using effective teaching methods to create stimulating learning contexts that promote mental engagement and motivation to learn and master new skills can be critical to the effectiveness of physical education programs, for the improvement of executive functions and academic performance in primary school children.

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