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Original Article

Exploring the relationship between physical activity and cognitive function in children

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Abstract
In recent years, scientific discussions have focused on the effect of physical activity (PA) on cognitive development in children. In this study, we performed an in-depth analysis of existing research on the influence of PA on children's cognitive function. Our objective was to identify the most effective approaches and settings for enhancing cognitive function through PA interventions. A literature review was conducted using Google Scholar, PubMed, Scopus, and Web of Science, focusing on studies published between January 2016 and March 2024. The following search terms were used for each database: physical activity, children, and cognitive skills. This work included experimental studies, meta-analyses, systematic reviews, and scoping reviews. Of the 19 articles included, 7 focused on cognitively engaging PA games, 4 on general PA, 3 on outdoor PA, and 1 on the design of play environments. The studies reported various settings: four in school sports facilities, three in school classrooms, one in an extracurricular sports facility, one in a schoolyard, one in indoor and outdoor sports facilities, and one in a school laboratory. The results indicate that cognitively engaging PA games enhance executive functions, while general PA is associated with improvements in school performance. The included studies suggest adopting methodologies based on PA's ecological–dynamic approach (EDA) principles to improve cognitive functions. In conclusion, future research could explore the effect of PA interventions grounded in the dynamic ecological approach on various cognitive abilities, such as creative thinking and problem-solving. Our goal is to encourage collaboration among the scientific community, educational institutions, and teacher training programs to promote these methodologies in educational settings.
Keywords: cognitive skills; physical education; ecological-dynamic approach

Introduction

Increasing attention is being paid in current investigations to the role of cognitively stimulating physical activity and outdoor play on cognitive function. Regarding the influence of cognitive functions, some researchers, including Pesce C. (2012), Rudd et al. (2020), and Vasilopoulos et al. (2023), propose a shift from an exclusive focus of "quantity" to promoting the "quality" of physical activity in order to support cognitive development. In this regard, the concept of "cognitively engaging" physical activity was introduced to highlight how it can influence cognition through cognitive efforts during exercise.

High-quality motor activity should be rich in coordinative, cognitive, and social interaction elements, in order to promote holistic development, not only in terms of physical efficiency and coordination but also in cognitive functions and life skills. This approach aims at the complete well-being of the child and the future adult (Kolovelonis et al. 2022).

In designing effective physical activity lessons, it is crucial to consider the interconnection between the physical and cognitive domains, although these aspects are often treated separately. In fact, more emphasis is usually placed on the development of physical skills at the expense of cognitive skills (Pesce et al. 2017; Kolovelonis & Goudas 2022). Proposing physical activity lessons with cognitive demands can help improve children's attention span by promoting meaningful learning (Schmidt et al. 2016). Cognitively engaging physical activity benefits children's overall development by enhancing their physical, emotional, social, and cognitive abilities (Bailey 2018; Bedard et al. 2021; Kolovelonis and Goudas 2022; Kolovelonis et al. 2022; Kolovelonis and Goudas 2023).

Unfortunately, in some cases, the environment of traditional classrooms can be limiting for physical activity (Beddoes et al. 2020). Therefore, it is essential to improve and expand opportunities for physical activity involvement (Abi Nader et al. 2018), as it can bring both physical and cognitive benefits.

Webster (2015) introduces two approaches to ensuring that there is opportunity for movement during lessons:

- incorporating physical activity during teaching activities, so that learning takes place through the active participation of students;
- scheduling short physical activity breaks between lessons.

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To these two strategies by Webster (2015), Alvarez-Bueno, et al. (2017), propose to include physical activity during recreation, to achieve greater psychophysical benefits. Incorporating physical activity during school lessons can make the learning environment dynamic and engaging, and it also contributes to improving students' academic performance (Schmidt et al. 2016; Alvarez-Bueno et al. 2017; De Greeff et al. 2018).

Pesce et al. (2016) support the notion that physical activity positively affects children's motor and cognitive development. They highlight the significance of providing age-appropriate physical activity games that utilize the principles of practice variability (Pesce et al. 2019). Therefore, to gain benefits from merging motor and cognitive demands into a single activity (Wollesen et al. 2022) it is necessary to design physical activity games that include significant cognitive challenges (Li et al., 2020).

These activities can be crafted based on fundamental principles like contextual interference, cognitive engagement, and exploration (Tomporowski et al. 2015). In this way, it is possible to stimulate creativity, cognitive flexibility and the ability to adapt to changing situations in children. Kolovelonis and Goudas (2023) noted that adhering to the three principles mentioned earlier when designing games can lead to beneficial impacts on children's executive functions. Additionally, they found that physically engaging activities incorporating cognitive elements generate greater interest and enjoyment compared to conventional activities (Kolovelonis and Goudas 2023; Kaloka et al., 2024).

In addition, to cognitive functions Rodriguez-Ayllon, et al. (2019) suggest implementing games to promote the psychological well-being of students. Another element to consider during the development of school-age children is outdoor play, which offers many opportunities including the chance to play freely, interact with nature and develop physical, cognitive and social skills (Cetken-Aktas & Sevimli-Celik, 2023). Outdoor play promotes the development of important skills, including assessment and risk management (Obee et al., 2021). It also helps children improve attention, behaviour, and inhibitory control, all important factors for learning (Lundy & Trawick-Smith, 2021). Well-designed outdoor play areas (Koepp et al., 2022), should allow children to dig, collect, climb, build and hide (Cetken-Aktas & Sevimli-Celik, 2023).

In the realization of environments dedicated to children it is necessary to consider their needs, expectations and interests, therefore, to adopt a child-centred perspective (Cetken-Aktas & Sevimli-Celik, 2023).

According to the work of the Children and Nature Network (2019), outdoor play is characterized by four main elements: imagination, construction, sensory richness and cooperation. With outdoor play, children can interact with elemental nature: rocks, earth, trees, insects, flowers, mud and water.

The National Association for the Education of Young Children (2019) recommends an outdoor space appropriate to the number of children who can be present outdoors at the same time, to allow children to move freely, interact with nature and play creatively. In this context, it is interesting to consider the importance of the ecological-dynamic approach in the field of physical activity. Indeed, the ecological-dynamic approach stands out for its inclusiveness and effectiveness; it promotes the development of motor skills through the interaction between person, task, and environment (Rudd et al. 2020; Rudd et al. 2021; Hulteen et al. 2023). This approach combines complexity science and ecological psychology, highlighting the importance of constraints on behavior, which are considered fundamental to a unifying theory of sport performance. The emergence of movement is driven by constraints that influence an individual's cognitive, functional, and structural capabilities, including emotional states, environment, and task requisites (Woods et al. 2019). In particular, task constraints are linked to performance and all its components, namely the rules of the game, the equipment used, and the objectives to be achieved (Romano et al. 2023).

The constraints-based approach is a model of non-linear pedagogy, which is based on the principles of non-linear dynamic systems such as self-organization and co-adaptation, favoring the search for effective motor solutions (Coppola al. 2021). Also, Rudd et al. (2020; 2021) emphasize that adopting an ecological-dynamic approach rather than a linear one is preferable, as it may be limiting for students with different levels of ability or learning modes. The ecological-dynamic approach and non-linear pedagogy offer avenues for fostering holistic student development. A key element of both approaches involves establishing learning environments conducive to transferring learned knowledge to novel contexts. This transfer process holds significant weight as it amplifies cognitive adaptability and reinforces problem-solving prowess (D'Anna et al. 2022). The ecological-dynamic approach also influences the cognitive dimension, particularly in the learning process of movements. Indeed, according to Renshaw et al. (2022) and Button et al. (2020), physical activity should provide opportunities to "train" cognitive skills, including attention, through an initial phase of search and exploration, discovery, and stabilization. Students learn to perceive affordances and use them to regulate their actions (Adolph & Hoch 2019; Button et al. 2020).

The processing of affordances and stimuli present in the environment facilitates the manifestation of various motor responses within the ecological-dynamic paradigm (Coppola et al. 2022).

The correlation between physical exercise and the ecological-dynamic approach stimulates the advancement of cognitive, personal, and social aptitudes, consequently enhancing the holistic welfare of the student (Coppola et al. 2024).

The aim of this study is to analyze scientific research examining the impact of physical activity on cognitive functions in school-age children and to identify the most effective methodologies and approaches for enhancing these cognitive functions.

Materials and methods

Search strategy

Literature research in Google Scholar, PubMed, Scopus, and Web of Science was conducted in this study. The following search terms were entered for each selected database: physical activity; children; cognitive skills. The criterion for inclusion in the selection of articles is related to the date of publication; in this case, studies published between January 2016 and March 2024 were selected.

Inclusion and exclusion criteria

To be included in the study, articles had to meet the following criteria:
- Type of study: systematic reviews, meta-analyses or experimental studies;
- Participants: preschool children;
- Interventions: physical activity lessons;
-results: school performance and cognitive function.

Any studies not meeting the eligibility criteria or involving clinical samples were excluded from the analysis. Additionally, irrelevant or unrelated articles were removed, resulting in 19 articles being included in the study.

Data analysis

Each selected studies were evaluated to extract information regarding study design, objectives, participants, physical activity intervention, and influence on cognitive functions.
The following information was extracted from each article: (1) authors, year and title of the study; (2) sample characteristics number and age of participants; (3) setting; (4) methodology; (5) results; (6) area of interest.

Results

The characteristics of the studies included are shown of the tables below. Specifically, Table 1 shows the experimental studies (12), while Table 2 shows the meta-analyses (3), systematic reviews (1) and scoping review (1).

Of the 19 articles included, 7 deal with cognitively engaging physical activity games; 4 with physical activity in general; 3 with outdoor physical activity; and 1 with the design of play environments.

Different settings are present in the reported studies, namely: 4 school sports facilities; 3 school classrooms; 1 extracurricular sports facilities; 1 school yard; 1 indoor and outdoor sports facilities; and 1 school laboratory. In terms of participant characteristics, the age of participants ranges from 3 to 14 years old.

Table 1: experimental studies on physical activity and cognitive function

Authors, year and title	Sample	Age (yrs)	Setting	Methodology	Result	Area of interest
Kolovelonis & Goudas 2022. *Exploring the effects of three different types of cognitively challenging physical activity games on students' executive functions and situational interest in physical education.*	140	9-10	School sports facilities (basketball court, volleyball court and courtyard)	Design fluency test; situational interest scale	The findings offer proof to endorse the utilization of physically engaging activities that stimulate cognition in order to involve students in physical activity and trigger their executive functions.	Executive functions
Bedard et al. 2021. *Examining the effects of acute cognitively engaging physical activity on cognition in children.*	48	6-9	Classroom of the school	Eriksen Flanker Modified Task.	The findings do not back up the hypothesis that engaging in cognitively stimulating physical activity enhances cognitive performance compared to non-cognitively stimulating physical activity or sedentary behaviors.	There are no significant differences
Kolovelonis & Goudas 2023. *The Effects of Cognitively Challenging Physical Activity Games versus Health-Related Fitness Activities on Students' Executive Functions and Situational Interest in Physical Education: A Group-Randomized Controlled Trial.*	102	9-10	School sports facilities (basketball court, volleyball court and courtyard)	Design fluency test; situational interest scale.	Cognitively demanding physical activity games have the potential to positively impact both students' executive functions and their situational interest.	Executive functions; situational interest
Kolovelons et al. 2022. *The effects of a cognitively challenging physical activity intervention on school children's executive functions and motivational regulations.*	99	9-10	School sports facilities (basketball court, volleyball court and courtyard)	Design fluency test; Stroop tests and Eriksen flanker	The intervention positively impacted executive functions and endorsed the revised design of physical activity programs aimed at simultaneously enhancing children's physical and cognitive development.	Executive functions

Schmidt et al. 2016. *Classroom-based physical activity breaks and children's attention: Cognitive engagement works!*	92	11-12	School classrooms	d2-R; PANAS-C; Borg scale RPE; RCE	A short cognitively engaging activity helps capture children's attention at school.	Attention
Beddoes et al. 2020. *Acute physical activity and cognitive performance among elementary schoolchildren.*	465	School age	School classrooms	Trail Making Test; a visual memory task; timed math test; acceleromet ers	Although PA differed significantly between the high and low PA groups, no significant differences in cognitive performance was observed between the two groups.	No significant differences emerged
Pesce et al. 2016. *Deliberate play and preparation jointly benefit motor and cognitive development: mediated and moderated effects.*	460	5-10	Extracurric ular sports facilities	Movement Assessment Battery for Children	Children who participated in the "enriched" intervention exhibited greater improvements across all motor coordination assessments.	Motor coordination
Koloveloni s & Goudas, 2023	144	9-10	School sports facilities (basketball court, volleyball court and courtyard)	Design fluency test; situational interest scale.	Games that involve cognitively engaging physical activities positively impact students' executive functions.	Executive functions
Cetken- Aktas & Sevimli-Celik, 2023. *Play preferences of preschoolers according to the design of outdoor play areas.*	102	3-6	Schoolyard	Three dimensional tool; Play Observation Scale	Through the design of play areas, cognitive and social play can be promoted by providing children with stimulating and inclusive environments. To promote development and wellbeing.	Global development and wellbeing
Lundy & Trawick-Smith, 2021. *Effects of active outdoor play on preschool children's on-task classroom behavior.*	21	3-5	Indoor and outdoor sports facilities	Direct observations	Active play in the park can enhance the learning process.	Learning
Koepp et al., 2022. *Preschoolers' executive functions following indoor and outdoor free play.*	72	3-6	School laboratory	ActiGraph GT3X; short game-like tasks.	Children showed greater control of attention in the classroom after 60 minutes of unstructured outdoor play compared with 60 minutes of indoor play.	Attention
Kaloka et al. 2024. *Improvement of Executive Function Through Cognitively Challenging Physical Activity with Nonlinear Pedagogy In Elementary Schools.*	145	9-11	School sports facilities	Design fluency test; situational interest scale.	Students who took part in cognitively demanding, nonlinear physical games showed greater improvements in executive functions compared to those who practiced soccer or athletic skills.	Executive functions

Kolovelonis and Goudas (2022) investigated how three distinct types of mentally stimulating physical games impacted students' executive functions and situational interest. Their findings revealed notable enhancements in the executive functions of students who engaged in a solitary physical education session involving these games, compared to those in the control group. Moreover, all three game types proved equally effective in augmenting students' executive functions, with no noteworthy variances observed among them. Furthermore, these games fostered a favorable situational interest among the students.

Bedard et al. (2021) explored on executive functions, the impact of three different activities: cognitively engaging physical activity; physical activity and cognitive activity. The findings showed no significant differences among these activities. In particular, the physical activity group with cognitive involvement showed apparently lower results than the other two groups.

Kolovelonis and Goudas (2023) examined how cognitively challenging physical activity games affect students' executive function and interest. These games were found to significantly enhance executive function, especially inhibition and cognitive flexibility, compared to health-related fitness activities. Additionally, the games generated higher levels of interest and enjoyment. Another study by Kolovelonis et al. (2022) assessed the impact of an intervention involving cognitively engaging physical activity games on school-age children. After the intervention, children showed significant improvements in executive functions, especially inhibition.

Schmidt et al. (2016) investigated how physical exertion and cognitive engagement impact elementary school children, concluding that a brief, cognitively engaging activity enhances children's attention at school. Beddoes et al. (2020) explored the effects of classroom physical activity (PA) on school-age children, dividing them into treatment and control groups for analysis. Results showed that children in the two groups showed no significant differences in cognitive performance. However, when the children's motor activity decreased to a low level or became vigorous, the children's performance in some cognitive tasks decreased.

Pesce et al. (2016) examined how an enriched physical activity intervention influenced school-age children, revealing that it enhanced motor skills and inhibitory ability, particularly notable in children who regularly engaged in outdoor activities.

Kolovelonis and Goudas (2023) assessed the impact of cognitively engaging physical activity games on students' executive functions, finding positive effects on both inhibitory control and cognitive flexibility.

Cetken-Aktas & Sevimli-Celik (2023) noted that through the design of play areas, cognitive and social play can be promoted by providing children with stimulating and inclusive environments. To promote development and well-being. In order to promote cognitive development, it is preferable to create a play environment characterized by natural elements and open spaces.

Lundy and Trawick-Smith's (2021) study showed that physical activity in the park can improve behaviour on the task in subsequent learning situations.

Koepp et al. (2022) analysed the influence of outdoor play on preschoolers' executive functions. Children showed better control of attention in the classroom after outdoor play compared with indoor play.

Kaloka and colleagues (2024) investigated how mentally challenging physical activities, involving nonlinear pedagogical games, influenced students' executive functions and situational interest. Their findings demonstrated that these games enhanced students' executive functions to a greater extent when compared to traditional sports like football or athletics.

Table 2: meta-analysis, systematic review and scoping review on physical activity and cognitive function.

Authors, year and title	Number of studies	Age (yrs)	Methodology	Results	Area of interest
De Greeff et al. 2018. *Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis.*	31	6-12	Studies included: (a) examination of how physical activity impacts executive function, attention, and/or academic achievement; (b) publications composed in English and released from 2000 to April 2017;(c) age between 6 and 12 years, (d) random assignment or a pairing with appropriate adjustments for any pre- test differences (e) inclusion of outcome variables measuring executive function, attention, or school performance on an interval or ratio level scale.	Positive outcomes have been identified concerning the impact of physical activity on executive functions, attention, and academic achievement in preadolescent youngsters.	Executive functions; attention; academic performance
Wollesen et al. 2022. *Effects of cognitive-motor dual task training on cognitive and physical performance in healthy children and adolescents: A scoping review.*	8	4-14	Studies included: (1) published in either English or German; (2) available in full version; (3) involving participants aged between 4 and 21 years old; (4) incorporating dual tasks as a component of the intervention; (5) administering one or more training sessions; (6) assessing at least one cognitive or motor outcome.	Dual-task training interventions have the potential to enhance both physical and cognitive functions in children and adolescents.	Physical functions; cognitive functions
Li et al. 2020. *The effects of chronic physical activity interventions on executive functions in children aged 3–7 years: A meta-analysis.*	10	3-7	Studies included: (1) children between the ages of 3 and 7 years old; (2) long-term physical activity intervention programs; (3) assessment of executive function performance, encompassing inhibition, working memory, and/or cognitive flexibility; (4) intervention studies featuring a suitable control group to differentiate causal effects; (5) publication in peer-reviewed journals and written in either English or Chinese.	Chronic PA interventions have small but positive effects on executive functions.	Executive functions
Alvarez- Bueno, et al. 2017. *Academic achievement and physical activity: a meta-analysis.*	26	4-13	Inclusion criteria: (1) healthy children and adolescents of developmental age; (2) exercise programs aimed at enhancing or enriching AF sessions; (3) consequences on academic performance; (4) randomized controlled trials (RCTs), quasi-experimental studies, and pre-post controlled studies.	Physical education enhances classroom behaviors and academic performance.	School performance

Rodriguez-Ayllon et al. 2019. *Role of physical activity and sedentary behavior in the mental health of preschoolers, children and adolescents a systematic review and meta-analysis.*	114	3-18	Inclusion criteria: (1) intervention studies and prospective longitudinal and cross-sectional studies centered on physical activity, sedentary behavior, and mental health; (2) written in English or Spanish; (3) encompassing preschool age (2-5 years), children (6-11 years), and adolescents (12-18 years); (4) examining the relationship between physical activity and/or sedentary behavior and at least one aspect of psychological distress and/or psychological well-being.	Physical activity had positive effects on adolescents' mental health; moreover, it was inversely related to psychological distress and positively related to psychological well-being.	Psychological well-being
Bidzan- Bluma & Lipowska, 2018. *Physical activity and cognitive functioning of children: a systematic review.*	58	Early, middle and late childhood	The key words applied in the research were: Children; cognition; cognitive function; physical activity and brain.	The results suggest that the practice of physical activity positively influences cognitive and emotional functions.	Cognitive functions; emotional functions
Alvarez- Bueno et al. 2017. *The effect of physical activity interventions on children's cognition and metacognition: A systematic review and meta-analysis.*	36	4-18	Inclusion criteria: (a) healthy children aged 4 to 18 years; (b) physical activity programs designed to enhance or augment physical activity sessions; (c) evaluation of cognitive performance focusing on non-executive cognitive functions, central executive functions, and/or metacognition; (d) randomized controlled trials (RCTs), non-RCT studies, and pre-post controlled studies.	Physical activity programs benefit multiple aspects of nonexecutive, executive and metacognitive functions in children and adolescents.	Executive and nonexecutive cognitive functions; metacognitive functions

The meta-analysis conducted by De Greeff et al. (2018) examined the impact of physical activity on executive function, attention, and academic performance in children aged 6-12 years. Their findings indicated that short-term physical activity has a slight to moderate beneficial influence on attention. Additionally, long-term physical activity interventions were associated with improvements in executive functions and academic performance. Moreover, physically engaging activities that stimulate cognition demonstrated a moderate to significant positive effect on executive functions.

The scoping review by Wollesen et al. (2022) examined cognitive-motor training interventions, divided into general and specific DT training. Both forms of training demonstrated improvements in both cognitive and motor performance. Li et al. (2020) conducted a meta-analysis investigating the impact of chronic physical activity interventions on executive functions in children aged 3-7 years. Their findings suggested a positive albeit modest effect of such interventions on executive functions.

Alvarez-Bueno et al. (2017) assessed the influence of physical activity (PA) on various aspects of academic performance and classroom behaviors. Their results demonstrated that engagement in physical education enhances both behavior and academic performance. Rodriguez-Ayllon et al. (2019) conducted a review exploring the relationship between physical activity and mental health in children and adolescents. They found that exercise interventions among adolescents had a slight positive effect on mental health. Moreover, physical activity was associated with better psychological well-being and lower psychological distress, while sedentary behavior correlated with depression and inversely with life satisfaction and happiness in children and adolescents. Bidzan-Bluma & Lipowska (2018) reviewed the connection between physical activity and cognitive function across different stages of childhood. They concluded that increased physical activity leads to enhancements in cognitive function, particularly in working memory, visuospatial memory, and cognitive flexibility, regardless of children's age. The study by Alvarez-Bueno et al. (2017) illustrated that physical activity programs yield benefits across various aspects of non-executive, executive, and metacognitive functions in children and adolescents.

Discussion

In this study, was conducted an analysis of 19 scientific papers that explored the impact of physical activity on cognitive functions in school-aged children. The reviewed studies consistently highlight the effectiveness of cognitively engaging physical activity games. These results indicate that such games can positively affect executive functions. To maximize cognitive benefits, it is necessary to select and design physical activities that engage both the body and the mind, as reported by Kolovelonis & Goudas (2023; 2022).

Furthermore, the implementation of these activities has been shown to increase situational interest and enhance student engagement, according to Kolovelonis & Goudas (2023).

Observations from Wollesen et al. (2022) and Schmidt et al. (2016) indicate that children participating in cognitively engaging activities exhibit improvements in attention and processing speed. These findings align with the results of a study by Kaloka et al. (2024), which also supports the effectiveness of cognitively engaging physical activity games. Furthermore, Kaloka et al. introduce the concept of nonlinear pedagogy games, which engage students in unpredictable, changing, and cognitively complex conditions, requiring both physical and mental effort. Several comprehensive studies conducted by Li et al. (2020), Rodriguez-Ayllon et al. (2019), Bidzan-Bluma and Lipowska (2018), De Greeff et al. (2018), and Alvarez-Bueno et al. (2017) collectively highlight the diverse advantages of physical activity for students. These benefits encompass improvements in executive functions, psychological well-being, learning outcomes, and school performance. In their respective meta-analyses, Li et al. (2020) and De Greeff et al. (2018) specifically investigated the influence of physical activity on executive functions among children within different age groups, namely ages 3-7 years and 6-12 years. Both analyses reached the consensus that engaging in physical activity could yield positive effects on children's executive functions.

Additionally, Rodriguez-Ayllon et al. (2019) and Alvarez-Bueno et al. (2017) have reported benefits associated with physical activity in their respective studies. Specifically, the findings from the meta-analysis by Rodriguez-Ayllon et al. (2019) suggest that an increase in physical activity and a decrease in sedentary behavior can enhance the psychological well-being of children and adolescents. Moreover, Alvarez-Bueno et al. (2017) emphasized that increasing physical activity interventions during school hours can enhance student performance and behavior. Alvarez-Bueno et al. (2017) concluded through their systematic review and meta-analysis that interventions involving physical activity effectively support the development of cognitive functions in children, spanning both nonexecutive and executive functions across various levels. Additionally, they found that regular physical activity not only enhances cognitive functions but also improves verbal abilities.

Bidzan-Bluma and Lipowska (2018) further emphasized the role of physical activity in facilitating vocabulary acquisition in a new language, as well as enhancing spelling, language comprehension, and the ability to detect syntactic errors. However, despite the documented positive impacts on cognitive and verbal functions, Bedard et al. (2021) did not find significant differences in executive functions among groups engaged in physically and cognitively engaging activities, those solely involved in physical activity, and those focused exclusively on cognitive tasks.

It is possible that the cognitively engaging physical activity games did not achieve a sufficient level of complexity to stimulate executive functions effectively. Additionally, the duration and intensity of the physical activities may not have been adequate to yield significant cognitive benefits. The research carried out by Beddoes et al. (2020) revealed that short physical activity sessions lasting only 10 minutes, with moderate or low intensity, did not yield significant differences in cognitive performance between the groups undergoing treatment and the control groups. This implies that the volume, duration, and intensity of the physical activity were not adequate to provoke an immediate cognitive response. The study suggests that integrating moderate-intensity physical activity sessions into the school schedule might be beneficial for enhancing children's cognitive performance. Furthermore, as indicated by subsequent studies, outdoor physical activities can also contribute to the development of cognitive functions.

In a study by Lundy and Trawick-Smith (2021), it was observed that children who engaged in 30 minutes of park play before participating in a learning activity demonstrated improved task behavior compared to those who had not played in the park. Additionally, outdoor physical activity appeared to enhance the children's ability to concentrate on cognitive tasks. Similarly, Koepp et al. (2022) reported that children who spent 60 minutes playing outdoors exhibited better attention control in the classroom than those who had played indoors. The outdoor environment, offering greater freedom of movement and exploration opportunities, seems to aid in developing their attention and concentration skills.

Research conducted by Pesce et al. (2016) found that a program combining enriched physical activity with regular outdoor play had positive effects on students' executive functions, particularly enhancing inhibitory control and cognitive flexibility. Moreover, when designing both outdoor and indoor play areas, it is crucial to adhere to the principles of the ecological-dynamic approach, which significantly influences how children interact and engage in play. To better support cognitive development, creating play environments that incorporate natural elements and expansive open spaces is recommended, as highlighted by Cetken-Aktas & Sevimli-Celik (2023)."

Conclusion

The studies reviewed provide comprehensive evidence that physical activity, particularly when combined with highly cognitively engaging activities, can significantly improve cognitive functions in children and adolescents. Many of these studies confirm the effectiveness of physical activity games that challenge students with unpredictable and dynamic conditions. Additionally, although not always explicitly stated, the methodological principles of the ecological-dynamic approach are often implied. These principles, which advocate for engaging with a stimulating environment, are recognized as beneficial for enhancing cognitive functions.

The findings of this research suggest that increasing physical activity and reducing sedentary behavior can significantly enhance children's physical, mental, and social well-being. In light of these findings, it is essential to refine and apply methodological approaches that have proven effective in improving children's cognitive performance and fostering their overall development. Consequently, to effectively implement educational and training initiatives aimed at holistic development during formative years, a robust collaboration among the scientific community, educational institutions, and teacher training programs is indispensable. This collaborative approach is crucial to leverage current scientific evidence for optimal developmental outcomes.

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