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Review

Physical Activity and Academic Performance in School-Age Children: A Systematic Review

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Abstract: This brief review aims to empirically summarize the expansive and ever-growing literature about the impact of physical activity interventions on cognitive function and academic performance. To better understand these relationships, this overview included research from different physical activity settings, such as school-based physical education, classroom-based physical activity and extracurricular physical activity. Given the findings adduced from the literature on this field, it could be argued that physical activity produces important changes in the brain, which mediate enhancements in cognitive performance as well as academic achievement. Therefore, the aim of this work is to analyze how physical activity may provide different pathways to improve cognitive health and academic performance among school-age children.

Keywords: physical education; cognitive functions; academic achievement

1. Introduction

Physical activity (PA) has always been synonymous with well-being and health. Children who follow a healthy and active lifestyle build their healthy musculoskeletal system, reduce the risk of developing chronic disease, improve their mental processes and enhance their self-conception [1].

In addition to their well-known health consequences, it is broadly recognized that physical activity is favorably related to cognitive development, brain health and, consequently, academic achievement among children and adolescents [2–6].

This literature suggests that physical activity may affect academic performance across several direct and indirect physiological, cognitive, emotional, and learning determinants [4,7]. After all, youth who are engaged in the highest amounts of physical activity have the opportunity not only to enhance their physical and mental health but also to solidify their self-esteem and self-efficacy and, consequently, promote their academic achievement [8,9].

In this regard, there is evidence showing that cognitive processes are developed along with motor skills [10,11]. In fact, it has been proven that the presence of higher levels of motor coordination in children affects academic competence [12]. Moreover, the most recent evidence accrued in this field suggested that physical activity involving qualitative-type characteristics that are mentally demanding determines the development of procedural and declarative skills [13]. Children participating regularly in enriched, varied and diversified activities during physical activity programs will more easily reach their genetic potential for motor skill control, which underlies a lasting physical fitness during the course of life [14].

Throughout the years, two currents of thought have been proposed to help describe the relation between PA and cognition: physiological mechanisms and learning/developmental mechanisms. The first relied on the physical changes caused by exercise and included an increase in cerebral blood flow, changes in brain neurotransmitters, structural changes in the central nervous system and modified arousal levels. However, the learning/developmental mechanisms are built on learning experiences that become necessary for cognitive development [4].

Citation: Latino, F.; Tafuri, F. Physical Activity and Academic Performance in School-Age Children: A Systematic Review. *Sustainability* **2023**, *15*, 6616. https://doi.org/10.3390/su15086616

Academic Editor: Giuseppe Battaglia

Received: 11 January 2023
Revised: 6 April 2023
Accepted: 12 April 2023
Published: 13 April 2023

Advances in neuroscience have introduced meaningful progress in this field. In fact, the impact of PA on the health of youth is also related to improved brain structure and cognition [3]. In recent years, several studies analyzed this connection, considering the intensity and duration of the PA (quantitative aspect) while leaving out the cognitive involvement necessary to perform different types of it (qualitative aspect) [15]. In a review dating 2015, Tomporowski et al. [16], analyzed the impacts of acute and chronic exercise, distinguishing between those that belong to a quantitative approach (intensity and duration of exercise), and those that used an approach with qualitative characteristics (type and mental engagement). The authors argued that both types of exercise improve cognition, emphasizing how metacognitive mechanisms and their regulation plays a crucial role in children's behavior and academic success. In more recent years, many researchers have claimed that PA with cognitively engaging tasks is able to influence cognitive process and, consequently, academic performance [17]. Physical activities that involve complex coordination ability and rapid decision-making processes contribute more than any other to the improvement in the subsequent academic performance of children, especially in subjects that involve the use of logic, such as mathematics. This is because the less monotonous character and highly variable character of exercise involving a complex coordination of movements focuses children's attention, helping them to maintain a successful motivation to learning. In this case, a more successful form of exercise for children and adolescents could be sports games [18].

Furthermore, over the years, the study of mind–body relations was also explored from the perspective of the pedagogical, psychological and social sciences, as well as by the biomedical sciences. These approaches characterized the evolution, the interdisciplinary dialectic, the interpretations, and the study models. The scientific relevance of the evidence highlighted by these research areas regarding the relationship between body, movement, and cognitive functions led the scientific community to recognize a condition through which intellectual functions may be used, providing concreteness, and opportunities for expression. Consequently, the connection between learners and learning, and the relationship between body and cognitive function, led to a critical re-thinking of the educational and training practices adopted by schools at present [19]. The educational approach, in the context of physical activity, seeks to outline a field of intervention with a main focus on a person's growth and learning throughout their formative years, starting from the beginning of the school experience and considering the unity between psyche and action, and "actions" of the mind and "actions" of the body, as fundamental [20].

Thinking of physical activity in pedagogical terms means that the sensory–perceptive and affective experience intersect with the cognitive learning: it is through movement that children live in their own body, emotions, and feelings, which are then transformed into concepts and skills [21]. In other words, according to a pedagogical approach, cognitive processes linked to learning, through a dynamic means of exchange between social behavior and communicative systems, may be considered cognitive tools resting on motility.

Therefore, considering the evidence provided from the scientific literature, the relationship between a physically active lifestyle and cognitive function in youth plays a crucial role in academic performance. The research on this topic suggests that improvements in academic performance may be linked to several facets of physical activity. Consequently, the existing literature explores a great variety of variables [22].

In this review, we considered the two variables that are mainly involved, those related to plasticity, and those resulting from physical activity levels and type (i.e., aerobic exercise). Thus, to continue broadening the understanding of these relationships, the aim of the present report is to summarize the available findings exploring the effects of PA on cognition among youth aged 4–18 years. Specifically, this paper aimed to identify the key conditions that promote academic performance linked to PA. Further, this review attempted to help contemporary educational institutions to understand the importance of physical education, and its short- and long-term health benefits in the physical, emotional, social, and cognitive

spheres throughout a person's lifespan to demonstrate the necessity of allocating greater resources to relaunch children's participation in regular PA.

2. Methods

2.1. Research Question

This review presents four main reasearch questions:

1. In what way does physical activity affect cognitive development among children aged 4–18 years?
2. What are the key conditions that promote academic performance linked to PA?
3. What are the physiological, emotional, social, and cognitive factors through which physical activity promotes academic achievement?
4. How does a lack of PA affect an individual's behavior habits?

2.2. Selection Criteria

In this review of the literature, 11 studies were included; they analyzed the relationship between PA and academic performance. The search strategy of the selected studies was based on two main factors: physical activity and academic achievement. Therefore, some studies focused on the motor area in relation to the cognitive one, especially the influence on academic performance during development. Thus, studies that presented relevant information on PICOS systems and respected the inclusion criteria listed below were considered eligible for inclusion in this review. They were:

- Participants aged between 4 and 18.
- English-language publications.
- Time interval of studies between 2013 and 2023.
- Analysis of the following indicators: development of motor skills, cognitive development in terms of attention, memory, and academic achievement.
- Measures of school performance (academic outcomes).
- Inclusion of clear measures of physical activity: school physical education, active breaks at school, extracurricular physical activity.

Studies were excluded from the present review if they did not respect the above criteria or if they exclusively concentrated on the relationship between academic achievement and fitness test scores, rather than on the conduct of a physical activity protocol, and if they only focused on the variables of the sedentary lifestyle. In addition, reviews (systematics or meta-analysis), and unpublished studies (reviews were utilized only as a reference to detect the original search) were also excluded.

2.3. Search Strategy

The present systematic review was performed following the PRISMA statement guidelines to ensure that the document was properly structured and developed [23]. Two trained research teams carried out initial research questions. They were then modified according to the PICOS framework to develop the literature search strategies, taking into account the participants, intervention, comparators, outcomes, and study design elements. The scientific articles were identified using the following databases: Medline (PubMed), Google Scholar, Embase, Web of Science, and Cochrane Library. The selected studies were detected utilizing the following Boolean search syntax: "((“academic achievement” or “academic performance”) and (“physical activity” or “physical education”)”/“(cognition or “cognitive function”) and (training or “physical training”)”/“(“cognitive approach”) and (exercise or training))”. Then, the appropriate filters were added: text availability: full text; species: humans; languages: English. The search syntax employed for the PubMed database was a mix of the MeSH database and Boolean search syntax. The search strategy used for Web of Science was adjusted in a proper way. Once the selected articles were found, a further selection was performed according to the inclusion and exclusion criteria.

2.4. Identification of Studies

Studies were identified through a search of five databases (Pubmed, Google Scholar, Embase, Web of Science, and Cochrane Library). At the end of the selection process, 196 articles were extracted, of which n = 25 from Pubmed, n = 61 from Google Scholar, n = 30 from Embase, n = 25 from Web of Science, and n = 55 from Cochrane Library. Studies were identified by searching for studies of likely relevance to the review. Thus, every title and abstract was selected, removing review articles, unpublished studies, meta-analyses, case studies, practical guidelines and books (n = 82). Subsequently, the full text of the remaining 104 articles was assessed to verify their eligibility. Finally, 11 research articles specifically concentrating on PA and academic performance among school-age children and adolescents were included (Figure 1).

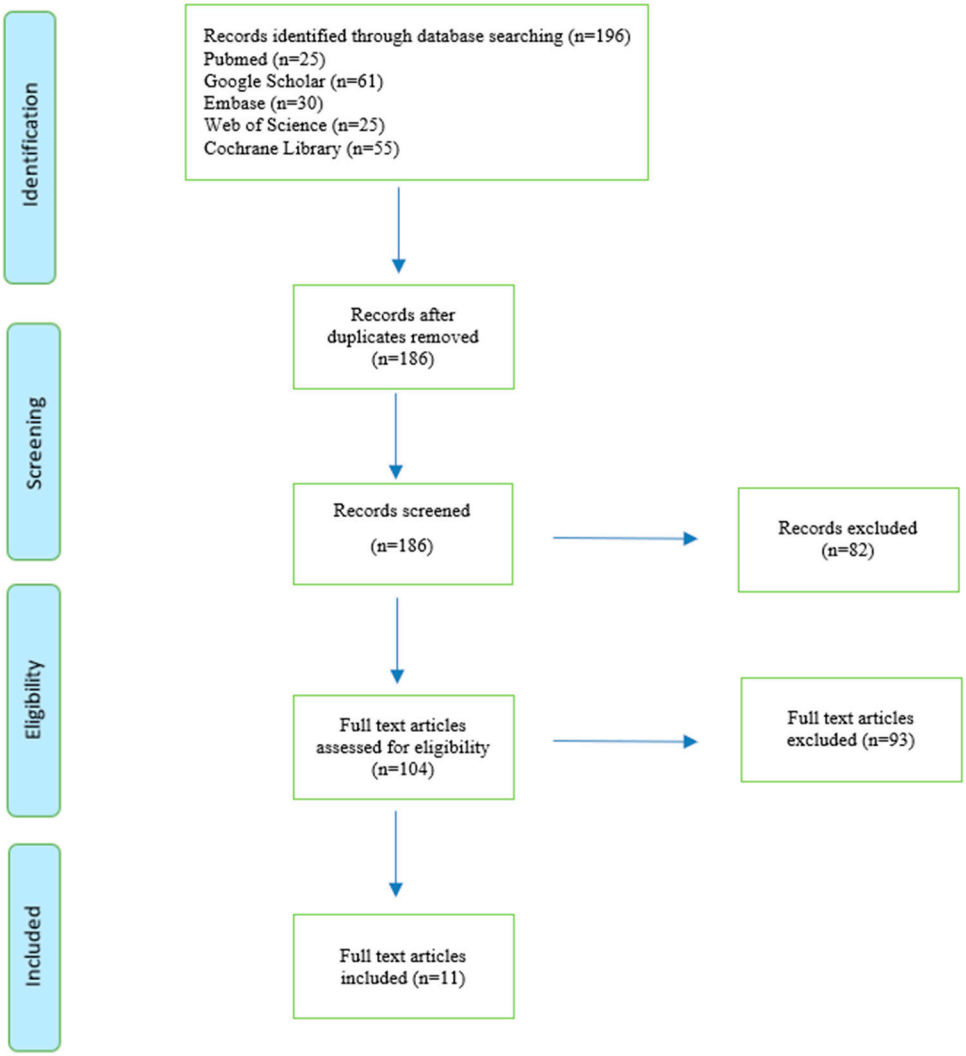

Figure 1. The study selection and eligibility screening flow according to PRISMA guidelines.

The Jadad Scale (modified version) was used to select the studies in a qualitative way (Table 1). It was used to assess the methodological quality of the studies selected and included in this systematic review. It ensured that the described studies were of high quality, since they have reported a high final Jadad score (from 4 to 5).

Table 1. The modified version of the Jadad quality scale.

Authors	Was the Treatment Randomly Allocated?	Was the Randomization Procedure Described and Appropriate?	Was There a Description of Withdrawals and Dropout?	Was There a Clear Description of the Inclusion/Exclusion Criteria?	Were the Methods of Statistical Analysis Described?	Jadad Score (0–5)
Chaddock, Erickson, Voss, Knecht, Pontifex, Castelli, Hillman, Kramer (2013) [24]	No	Yes	No	Yes	Yes	4
Hillmann, Hillman, Pontifex, Castelli, Khan, Raine, Scudder, Drollette, Moore, Wu, & Kamijo (2014) [25]	Yes	Yes	Yes	Yes	Yes	5
Mullender-Wijnsma, Hartman, de Greeff, Bosker, Doolaard, & Visscher (2015) [26]	Yes	Yes	Yes	Yes	Yes	5
Mavidili, Okely, Chandler, & Paas (2016) [27]	Yes	Yes	Yes	Yes	Yes	5
Donnelly, Hillman, Greene, Hansen, Gibson, Sullivan, Poggio, Mayo, Lambourne, Szabo-Reed, Herrmann, Honas, Scudder, Betts, Henley, Hunt, & Washburn (2017) [28]	Yes	Yes	No	Yes	Yes	4
Latorre Román, Pantoja Vallejo, & Berrios Aguayo (2018) [29]	Yes	Yes	Yes	Yes	Yes	5
Egger, Benzing, Conzelmann, & Schmidt (2019) [30]	Yes	Yes	No	Yes	Yes	4
De Bruijn, Kostons, Van Der Fels, Visscher, Oosterlaan, Hartman & Bosker (2020) [31]	Yes	Yes	No	Yes	Yes	4
Centeio, Somers, Moore, Kulik, Garn, & McCaughtry (2021) [32]	Yes	Yes	Yes	Yes	Yes	5
Latino, Cataldi, Bonavolontà, & Fischetti (2022) [33]	Yes	Yes	Yes	Yes	Yes	5
Masini, Sanmarchi, Kawalec, Esposito, Scrimaglia, Tessari, Scheier, Sacchetti, & Dallolio (2023) [34]	Yes	Yes	No	Yes	Yes	4

To assess risk of bias, an excel graph was used, as recommended by the Cochrane for the evaluation of risk-of-bias for randomized trials (Figure 2). This graph highlighted the transparency and methodological rigor of evidence synthesis results. It was performed for each included study and ensured the high methodological rigor of the included studies, as they showed low percentages for the risk of bias category.

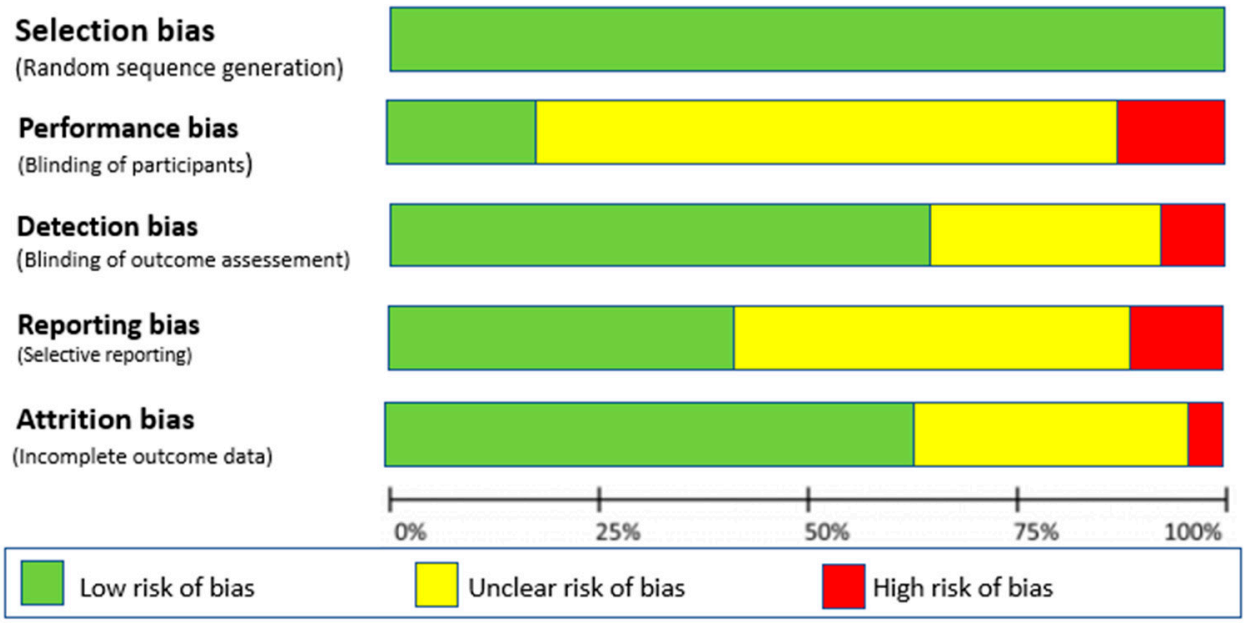

Figure 2. Risk of bias assessment graph.

2.5. Study Characteristics

This systematic review provides an analysis of 11 high-quality studies (Table 2) focused on physical activity and academic achievement in school-age youth, inquiring in depth about the impact of PA on cognitive function and academic performance. Some of these works regarded the effect of aerobic physical activity on brain and cognitive function (n = 3) [24,25,29], most of them (n = 7) [26–28,30–32] involved the relations between increasing PA, and scholastic achievement, and two focused on the cognitive involvement in PA [30,33], while the other works [32,34] focused on the relationship between body weight, cognitive function, and academic achievement (n = 1).

Table 2. Summary characteristics of reviewed studies.

Authors	Samples	Objectives	Procedures	Measures	Results
Chaddock, Erickson, Voss, Knecht, Pontifex, Castelli, Hillman, Kramer (2013) [24]	U.S.A. Participants: 23 healthy children; Average ages: 9.9 ± 0.5 years	2 groups assigned to the higher fit (n = 14) or wait-list (n = 9)	Authors employed fMRI to explore brain activity of children with higher or lower Fitness levels during early and late task blocks of a cognitive control flanker paradigm.	- ParvoMedics True Max 2400 (VO2max). - fMRI scans.	The present study suggests that children with higher fitness levels have a notable ability to activate frontal and parietal brain regions that determine higher-level cognitive control skills.
Hillmann, Hillman, Pontifex, Castelli, Khan, Raine, Scudder, Drollette, Moore, Wu, & Kamijo (2014) [25]	U.S.A. Participants: 221 healthy children; Average ages: 7–9 years	2 groups randomly assigned to the EG and CG	Children intermittently participated in at least 70 min of moderate-to vigorous PA.	- VO2peak - Modified flanker task. - Color-shape switch task. - EEG.	The intervention enhanced cognitive performance and brain function during tasks requiring greater executive control.
Mullender-Wijnsma, Hartman, de Greeff, Bosker, Doolaard, & Visscher (2015) [26]	Netherlands; Participants: 228 healthy children; Average ages: 8.1 years	2 groups randomly assigned to the EG and CG	The EG participated in physically active academic lessons and CG in regular classroom lessons. The intervention was conducted 3 times a week, for 21 weeks.	- Team heart rate monitors. - 20 m shuttle run test. - 1-Minute Test (reading). - Speed Test Arithmetic.	This study shows that classroom-based PA enhances the academic perfromance of 3-grade pupils.
Mavidili, Okely, Chandler, & Paas (2016) [27]	AUS; Participants: 87 healthy children; Average ages: 4.88 ± 0.5 years	3 groups randomly assigned to an integrated PA condition, an unintegrated PA condition, and a control condition without PA	The intervention consisted of physical activities integrated into a geography task.	- Geography task. - Actigraph accelerometer.	The present study provided positive evidence that the integration of PA into learning activities appears to be an enjoyable, engaging, and promising strategy for the improvement of learning performance in children.
Donnelly, Hillman, Greene, Hansen, Gibson, Sullivan, Poggio, Mayo, Lambourne, Szabo-Reed, Herrmann, Honas, Scudder, Betts, Henley, Hunt, & Washburn (2017) [28]	U.S.A.; Participants: 687 healthy children; Average ages: 7.6 ± 0.6 years	2 groups randomly assigned to the EG and CG	The classroom teachers in A + PAAC schools were trained to deliver two 10 min classroom-based PA 5 days/week over the 3-year intervention. Teachers in control schools were asked to continue to use traditional classroom instruction.	- Weschsler Individual Achievement Test-Third Edition (WIAT-III). - Kansas Assessment. - Eriksen flanker task. - Progressive Aerobic Cardiovascular Endurance Run (PACER-FITNESSGRAM). - ActiGraph GT1X portable accelerometer.	Based on the results, higher levels of PA during academic instruction time during school did not improve or diminish children's academic achievement.
Latorre Román, Pantoja Vallejo, & Berrios Aguayo (2018) [29]	Spain Participants: 96 healthy children; Average ages: 9.84 ± 1.12 years	2 groups randomly assigned to the EG and CG	The EG had previously performed aerobic games lasting 45 min in a physical education (PE) class	- Prueba de Imaginación Creativa-Niños test (PIC-N). - Rate of Perceived Exertion (RPE).	The findings suggest that acute aerobic exercise enhances students' creativity, which could be important for academic performance.
Egger, Benzing, Conzelmann, & Schmidt (2019) [30]	Switzerland; Participants: 142 healthy children; Average ages: 7–9 years	3 groups randomly assigned to one of three experimental conditions	Three programss with diverse levels of cognitive engagement and physical exertion: (1) the *combo group* with high levels of both cognitive engagement and physical exertion, (2) the *aerobic group* with low cognitive engagement and high physical exertion, and (3) the *cognition group* with high cognitive engagement and low physical exertion. The interventions were carried out two times in 10 min sessions per day lasting 20 weeks.	- ActiGraph GT3X. - Self-Assessment Manikin. - E-Prime Software - Heidelberger Rechentest (HRT 1–4). - Hamburger Schreib-Probe (HSP 1–10). - Salzburger Lesescreening. - Physical Activity Questionnaire for Children (PAQ-C). - Multistage 20 metre Shuttle Run test. - Körperkoordinationstest für Kinder.	These results suggest that the inclusion of cognitively engaging PA breaks seem to be a promising way to improve school children's cognitive functions.

Table 2. *Cont.*

Authors	Samples	Objectives	Procedures	Measures	Results
De Bruijn, Kostons, Van Der Fels, Visscher, Oosterlaan, Hartman & Bosker (2020) [31]	Netherlands; Participants: 891 healthy children; Average ages: 9.17 years	2 groups randomly assigned to the EG and CG	Intervention groups were randomly assigned to a 14-week aerobic or cognitively engaging intervention, receiving four physical education lessons a week (30 min). Control groups followed their regular PE lessons.	- ActiGraph GT3x +. - Stan < dardized test battery for Netherlands primary schools.	The results presented in this study suggest that activities that combine a moderate-to-vigorous intensity level with cognitive engagement will have the most beneficial effects on academic achievement.
Centeio, Somers, Moore, Kulik, Garn, & McCaughtry (2021) [32]	U.S.A.; Participants: 628 healthy children; Average ages: 9.46 ± 0.52 years	6 schools randomly assigned to the EG (n = 4) and CG (n = 2)	A random sample of fifth grade teachers integrated PA into their core curricula.	- Math computation (using AIM-Sweb). - Reading comprehension (using DIBELS).	This investigation provides evidence that youth who are more physically active tend to perform better academically. Activity breaks can improve students' reading and math achievements.
Latino, Cataldi, Bonavolontà, & Fischetti (2022) [33]	Italy; Participants: 88 healthy children; Average ages: 14 ± 0.33 years	2 groups randomly assigned to the EG and CG	Experimental group received 15 more minutes of CPA (with cognitive involvement) in addition to PE classes. Control group received regular PE lessons.	- 20 mSRT. - Push-up. - Curl-up. - Sit and reach. - Amos 8–15.	This study suggests that a physical activity program with cognitive involvement might be effective in terms of cognition and academic success, as well as improving students' physical fitness.
Masini, Sanmarchi, Kawalec, Esposito, Scrimaglia, Tessari, Scheier, Sacchetti, & Dallolio (2023) [34]	India Participants: 106 children (overweight and non-overweight); Average ages: 7.92 ± 1.4 years	cross-sectional study with 1 group assigned	Children' PA levels and sedentary behavior were monitored over a 7-day period.	- ZOOM-8 questionnaire. - Actigraph accelerometers. - WM assessment. - KIDMED. - BMI. - Backward digit span (WISC-IV).	This study supports the idea that as well as its importance for maintaining weight and reducing health risks in obese children, physical activity is a proficient startegy to improve children's mental functioning.

3. Results

At the beginning of this study, four main research questions were posited by the authors, namely:

1. In what way does physical activity affect cognitive development among children aged 4–18 years?
2. What are the key conditions that promote academic performance linked to PA?
3. What are the physiological, emotional, social, and cognitive factors through which physical activity promotes academic achievement?
4. How does a lack of PA affect an individual's behavior habits?

The findings of the present review have provided responses to the formulated hypotheses. These can be summarized in the following way:

3.1. Physical Activity Affects Cognitive Development via Different Molecular and Functional Brain Changes and Behavioral Mechanisms

In recent years, several studies have explored the effects of PA on brain plasticity, leading to the identification of different cognitive behavior enhancements [35]. In early academic papers, researchers mainly argued that youth with higher fitness levels showed a greater allocation of attentional resources to working memory [36]. Moreover, Sibley and Etnier [4], who, more than any other researcher, laid the groundwork for research in this field, confirmed the existence of a small but meaningful connection between PA and cognitive performance in school-aged children (aged 4–18), proposing that PA could be related to cognitive functions during development. Specifically, they found a significant connection between IQ and academic achievement, whereas no connection was found with memory. Their findings were meaningful because they were the first investigations in this field, hinting that PA may be beneficial for cognitive development.

Another important line of research was conducted by Stillman, Cohen, Lehman and Erikson [37], who proposed a conceptual model that identifies multiple ways in which modifications in brain structure, function and behaviors, as well as in socioemotional functions (mood, motivation, or sleep), may mediate enhancements in cognitive processes as result of physical exercise.

This model was the only one to emphasize the notion that mechanisms of physical activity on cognitive objectives may be outlined at multiple levels: the molecular and cellular mechanisms of PA (level 1), structural and functional brain changes (level 2) and behavioral mechanisms (level 3). Over the years, the debate about physical activity's link with cognition was restricted to explaining the molecular and cellular mechanisms of PA, ignoring levels 2 and 3. In their review, the authors focused on evidence of PA's mechanisms on cognition, as affected by structural and functional brain changes and behavioral mechanisms. According to the authors, brain morphology is linked to cognitive function and to PA. Specifically, their review suggests that PA raises brain volume, especially in the hippocampus. This modification of the volume partly explains the cognitive enhancements resulting from exercise. Moreover, they observed that modifications in white matter microstructure and increased cerebral perfusion seem to be a further mechanism of the effects of physical activity on cognition. Lastly, in response to exercise, some changes in brain function in the prefrontal cortex that improved executive functioning. Regarding the socioemotional functions, they concluded that sleep and mood might be behavioral mechanisms through which physical activity affects cognitive functions. In fact, PA improves cognitive performance, affecting sleep quality and efficiency. Higher levels of PA were linked to enhanced mood; low mood was connected with poorer performance in different cognitive tests. Therefore, the authors viewed mood as a means by which physical activity affects cognitive outcomes. These cognitive enhancements especially occur relative to executive functioning, attention, and memory.

3.2. The Key Conditions That Promote Academic Performance Linked to PA

In recent years, the research in this field has evolved considerably through studies born of necessity to better grasp the multidimensional relationship between PA and cognitive and brain functions. Much of the research focused on animals identified an enhancement of neurogenesis, synaptogenesis, angiogenesis, and the release of neurotrophins as neural mechanisms mediating the positive cognitive effects of PA [38]. These findings suggest that physical exercise can facilitate neuroplasticity and, thus, improve an individual's capacity to respond to new needs with behavioral adjustments [39].

PA has been connected with a higher release of neurotrophic molecules, such as brain-derived neurotrophic factor (BDNF), which enhances learning and cognition, and several molecular and cellular cascades. BDNF determines neuroprotection and encourages cell survival, neurite outgrowth, and synaptic plasticity [40]. Moreover, consistent PA can increase the number of neurons, dendrites, and synapses, fundamental structural elements placed across the central and peripheral nervous systems [3]. All these systems can facilitate learning and maintain cognitive functions. Recent evidence shows how the effects of physical activity on the brain can lead to favorable outcomes, such as improvements in attention, memory, and executive functions. In fact, physical activity, when conducted regularly, has also been found to promote structural modifications in the hippocampus, which is a significant area for memory [41].

Chaddock and colleagues [24] were the researchers that, more than any others, systematically demonstrated the impact of PA on brain structure and function. Moreover, they showed a significant and positive relationship between aerobic exercise, brain volume, and domains of cognition, such as memory. They reported that increased aerobic fitness were related to higher academic performance, better cognitive abilities, larger brain structures, and superior brain function in school-age youth (aged 8–9). Through the employment of functional magnetic resonance imaging (fMRI), the authors found that youth with higher fitness levels have an elevated capacity to trigger frontal and parietal brain regions that are significant for the monitoring and maintenance of higher-level cognitive control abilities, meaningful skills for academic outcomes. Furthermore, the authors reported that children with improved physical fitness had bigger bilateral hippocampal volumes and more affluent relational memory task performance than children who present with lower physical fitness. It is interesting to observe how these results differed from Sibley and Etnier's [4] meta-analysis, where the authors claimed that PA is not correlated with memory skills in children aged 4–18 years [42].

Hillman et al. [25] found that children participating in at least 70 min of moderate-to-vigorous physical activity (MVPA) per week for 9 months, aiming to increase aerobic fitness, positively enhanced the brain and behavioral factors of executive control. The authors suggested that fitness-related benefits appear to follow a dose–response relationship seen between percentage participation, brain function, and executive control. In addition, they demonstrated that brain and behavioral modifications occurred that correlated with the PA attendance rate. They showed that children with higher fitness levels, when engaged in the Eriksen flanker task (a test which requires resolving conflicts), were able to outperformchildren with lower fitness levels. Specifically, higher-fitness-level children managed to be more precise in trials, with fewer errors of commission. Therefore, the authors concluded that their brains are more responsive when monitoring conflict. In addition to behavioral measures, Hillman and colleagues collected event-related brain potentials (ERPs) arising from EEG activity in the course of the cognitive tasks (they used 64 electrodes to detect the P3 amplitude and latency indices). They showed that, when compared to controls, the trained children showed several modifications in the neural index of attention (P3 amplitude), processing speed (P3 latency), and enhanced performance throughout the executive control tasks, as result of the greater allocation of attentional resources and faster cognitive processing speed.

In 2018, Latorre Román, Pantoja Vallejo, and Berrios Aguayo [29] conducted interesting research, which involved 96 students assigned to an aerobic games group or to a no-exercise

control group. Their findings revealed that creativity, which is important for academic achievement, would appear to be affected by aerobic PA and may be observed after just one acute bout of exercise. In the opinion of the authors, this happens because the aerobic PA determines certain brain changes, which result in a direct neurochemical response that may improve cognitive performance.

3.3. The Physiological, Emotional, Social, and Cognitive Factors through which Physical Activity Promotes Academic Achievement

Several lines of empirical evidence agreed that increases in PA have been linked to enhances in both cognition and academic performance [27].

Scientific results suggest that a proper amount of PA offers children opportunities to enhance academic performance while promoting better physical and mental health [43]. This happens because most trained children have more efficient brain activation during cognitive tasks, better inhibitory control, superior working memory, and a higher attention span [44]. An increase in PA results in both short- and long-term benefits to academic achievement. After a few minutes of PA, pupils are better able to focus on classroom tasks, which can improve learning. Over time, when children are constantly engaged in PA, their better physical fitness can have additional favorable effects on academic performance in some topics, such as mathematics, reading, and writing [45,46].

Many studies have focused on increasing PA levels in school-aged youth.

Mavidili et al. [27] conducted a very promising study on 87 preschool healthy children recruited from 8 childcare schools. Children were randomly assigned to an integrated PA with a learning condition (geographic tasks), an unintegrated PA condition, or a control condition where no PA took place. The authors demonstrated that children engaged in both learning conditions (integrated and nonintegrated PA) showed a better performance than the children that performed under learning conditions where no physical activities took place. In fact, they obtained the best results on an immediate retention test, and on a delayed retention test (administered five weeks later). Moreover, children tested under PA conditions reported that their learning method was the most exciting and enjoyable. Therefore, the authors established that children with higher fitness levels showed improvements in cognitive functions. Moreover, a higher level of PA could improve school 'on-task' behavior. Lastly, they found that the greatest effects were observed when children engaged in aerobic PA.

In 2020, De Bruijn et al. [31] compared the impact of two types of PA on academic performance. The first one was aerobic PA, while the second one was cognitively engaging PA. The programs revealed meaningful dose–response effects, as children who were exposed to a higher level of moderate-to-vigorous physical activity performed better in mathematics, and spelling. They showed that moderate-to-vigorous PA and PA with cognitively engaging tasks had the most spread-out effects on academic performance. Thus, they suggested that it is significant to offer both quantitative and qualitative aspects of PA when aiming to improve academic performance.

Centeio et al. [32] examined the impact of integrating PA with elementary curricula on reading and math achievement in a primary school context. Thus, an integrative curriculum provides students with a global view of learning and can expand their cognitive skills, improving academic outcomes. This study was able to highlight the impact of a whole-of-school approach on academic performance. Moreover, the study used curriculum-based measures to assess the variables in question.

Mullender-Wijnsma et al. [26] conducted research based on evidence of the positive impact of MVPA on academic outcomes. Their study provided that the experimental group was engaged in classroom-based PA, while the control group participated in regular classroom lessons. They suggested that, in the long-term, regular moderate-to-vigorous physical activity could cause morphological changes, such as angiogenesis, neurogenesis, and synaptogenesis, in brain regions that are important for learning. In addition, the authors claimed that activity breaks could improve cognitive performance and classroom

behavior, as well as students' concentration skills. Lastly, the authors concluded that mathematics and reading were the school subjects that were most affected by PA. This depended on efficient and effective executive function, which have been related to PA and physical fitness.

Similarly, from 2013 to 2016, Donnelly et al. [28] conducted a study to evaluate the effects of classroom-based Pa on academic performance in primary school pupils (grades 2 and 3). Their intervention did not improve or diminish children's academic achievement, but they concluded that pupils received an additional 55 min./wk. of moderate-to-vigorous PA, which may be linked with both physical and mental health benefits, without decreasing the time dedicated to education.

Moreover, Egger and colleagues [30] examined the impact of qualitatively various physical activity breaks on youth's cognitive objectives. They allocated 142 children (aged 7–9 years) to 20 weeks of physically active lessons. They provided students with three conditions: (i) combo group, with high physical exertion and high cognitive engagement; (ii) aerobic group, with high physical exertion and low cognitive engagement; (iii) cognition group, lwith ow physical exertion and high cognitive engagement. Their findings suggested that the group that followed the program that offered high physical exertion and high cognitive engagement profited the most, displaying an enhanced shifting and mathematic performance. The group with low physical exertion and high cognitive engagement only showed improvements in mathematic performance. Lastly, the group engaged in high physical exertion and low cognitive engagement remained unaffected.

Over the years, most studies that explored the relationship between physical activity and learning considered only aerobic exercise, without paying attention to the cognitive involvement necessary to perform different types of physical activity (qualitative aspect) [15]. The lack of studies in this area has led to a deep divide in educational praxis [47]. In fact, teachers often have limited knowledge about which exercise is better to solicitate students' academic achievement.

In addition, a meaningful association has been shown between children's quality of experiences and cognitive and motor development [48]. The development of motor skills is, above all, a result of the opportunities provided by an enriched environment [49]. Different studies have demonstrated how physical activity performed in an enriched environment determined structural modifications to the brain, as well as behavioral changes, through an increase in physical activity and exploration, as well as learning, especially the spatial type and problem-solving abilities. This condition can determine a long-term potentiation within the hippocampus thanks to an activity-dependent increase in synaptic transmission [50]. An enriched environment refers to an environment that promotes social interaction and the development of higher cognitive, perceptual and motor skills. In other words, an environment that includes a number of complex and different visual, cognitive, motor, somatosensory and social solicitations. They are supported by motivation, attention, and interest. According to [51], the novelty and complexity of the motor tasks are likely the main factors behind the beneficial effects of the enriched environment. Exposure to a physically and cognitive stimulating environment (enriched environment) would affect the expression of neurotrophins [52] such as BDNF [53].

Most of the physical activity performed by children is characterized by group activities, which require complex cognitive skills to allow for children to cooperate with peers, anticipate the behavior of their opponents, employ different strategies, and adapt to the changing demands of the motor tasks that must be performed [54]. Even if the acquisition of these skills occurs faster when the tasks are presented in a simple and repetitive way, the maintenance and transfer of these competences are improved when the different parts of the activities are presented in a complex and random way [55].

In recent research, Latino et al. [33] investigated the effects of a 16-week physical activity program with cognitive involvement on student's learning outcome. They engaged 88 students who attended the first class of a high school, who were randomly assigned to an experimental group (EG) or a control group (CG). The EG participated in a program

called Action Class! This program added 15 more minutes of cognitively engaging PA to the physical education (PE) class (60 min, twice a week). The control group were involved in traditional PE lessons. The researchers claimed that a PA with cognitively engaging tasks is significant in improving cognitive functions and academic performance.

3.4. How the Lack of PA Works on Individual's Behavior Habits

Obesity can impair brain functions by affecting the brain's structures and processes. To demonstrate this, neuroimaging research in children demonstrates that obesity is associated with differences in white matter organization, especially in the frontal and temporal brain regions, and smaller grey matter volume in brain regions involved in executive function [56,57]. Unfortunately, according to the available data, youth pass their leisure time in sedentary activity, mainly watching television and playing on computers. Greater emphasis on enhanced opportunities for PA is clearly needed, particularly because the predominance of obesity is associated with a lack of PA, rather than increased food intake alone [58]. Global estimates show that 27.5% of adults and 81% of adolescents do not meet the 2010 World Health Organization (WHO) [59] recommendations for PA. Even in the latest Guidelines on PA and sedentary behavior (2020), the WHO provide advice for youth and adults regarding the frequency, intensity and duration of PA, which is needed to provide meaningful physical and mental health benefits to ensure healthy weight and general well-being.

Most studies carried out to date have drawn the same main conclusion, namely that children who enter school overweight report poorer future academic performance [60]. The experiment conducted by Masini et al. [34] provides an example of research on this topic. In their experiment, 106 overweight and non-overweight children were monitored for PA levels and sedentary behavior over a 7-day period. Their findings revealed that adherence to a healthy diet and a more active lifestyle improved executive function in a dose–response fashion among overweight children.

Centeio and colleagues [32], as a secondary aim of their research, examined whether academic achievement scores varied according to the BMI values of 5th-grade elementary students. At the end of the study, their findings corroborated the assumption that children who are more physically active tend to perform better academically. Overwhelming evidence about the negative relationship between fatness and academic achievement was confirmed by Donnelly et al. [28]. They suggested that school-based interventions that provided an increase in PA, primarily through PE, had the potential to reduce obesity among children, resulting in better academic performance. They show that increased BMI and higher level of fat mass were associated with a lower performance on cognitive control tasks, as well as a poorer academic performance. Hillman and colleagues [25] demonstrated that children who are involved in an after-school program, at the end of the study, showed larger enhancements in physical fitness, a reduction in body fat, and an increase in working memory compared to the waitlist group. Further, the authors observed that a lack of PA and aerobic fitness may be harmful to cognitive functions.

4. Discussion

This paper aims to explore and shed light on the existing literature on the impact of physical activity on cognitive functions and academic performance. In order to better understand these connections, this overview included the most important research paths from different physical activity settings, such as school-based physical education, classroom-based physical activity and extracurricular physical activity.

The evidence identified by this review encourages the idea that PA is a positive approach to improve cognition among school-aged children and adolescents. This occurs through several forms of PA, performed in different contexts and with different characteristics.

Advances in neuroscience and neuroimaging techniques have allowed for researchers to better grasp the effects of physical activity on the brain, from the body system level down to the molecular level [3]. Research carried out focusing on different areas of physical activity has developed this field of research and pinpointed different preliminary under-

lying processes. A deeper comprehension of the cognitive elements that are connected to academic achievement and could be susceptible to modification has been achieved. Thus, the latest findings have allowed for a better comprehension of the possible importance of PA to changes in brain structure [61].

Overall, the findings of the presented works indicate that PA, especially aerobic exercise, is meaningfully linked to students' cognitive function and their academic performance. However, this correlation is not as straightforward and clear, since it differs according to the study outcomes. Cardiorespiratory fitness can also mediate the relationship between PA and body weight [62]. Therefore, this is a visible mediation factor for academic success for overweight children [63]. Thus, according to the available literature on the relationship between PA and academic performance, it can be concluded that providing youth with the opportunity to be active can improve their physical and mental wellness and scholastic performance (Figure 3).

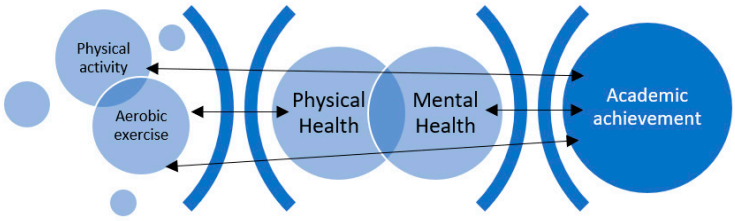

Figure 3. A conceptual model illustrating how increasing physical activity, especially aerobic exercise, may optimize academic performance through the improvement of physical and mental health.

In more recent times, the research has shown that there appears to be a differentiation in attentional levels depending on the type of exercise. Physical activity with coordinative and engaging tasks has been found to be more beneficial for children's attention than any other regular type of exercise [64,65].

Therefore, the current evidence meaningfully contributes to clarifying and understanding the proposal to increase school PA time to the detriment of classroom curricular time. However, findings in this area are still unclear and conflicting. Research about the correlation between active classrooms and academic performance is a complex field in an evident experimental stage, and still needs further study and verification to improve understanding [66]. Nevertheless, the presented evidence corroborates that increasing participation in physical activity could be closely related to the improvement in academic performance and cognitive functions, such as attention and memory. Pupils should have the opportunity to be involved in a wide range of PA, as physical and mental well-being can be achieved by the use of different approaches from those to which we are accustomed (i.e., active classroom lessons and active breaks with cognitive involvement) [67].

In recent years, related and emerging scientific research has been increasingly interested in exploring the correlation between adiposity, cognition, and academic performance. Several reports on this relationship found that a higher BMI and an increase in fat mass was associated with lower academic performance [68].

This negative relationship between lack of physical activity, obesity, and poor academic achievement could potentially be explained by lifestyle factors related to the energy–metabolic balance and changes in health habits [69]. Several studies suggest that childhood sedentarism not only affects physical health, but also cognitive and brain functions [70].

In this context, the comprehension of the social–cognitive theories allows for the realization of measures to maintain an active and healthy lifestyle during the life course. As part of physical activity, the science of behavioral changes is significant when encouraging the adoption of less sedentary behavior [71]. Behavioral change is described as a temporary or permanent reaction that is considered a change in an individual behavior that is regarded as harmful or unsafe to health. Thus, it is a challenging process, especially within the context of physical activity, as there are several factors promoting sedentarism [72]. At the same time, there are several factors that impact an individual's decision to engage in active or

sedentary behavior. These factors include a combination of personal, social, psychological, physiological and environmental elements. Thanks to their dynamic character, these factors modulate individual's targets and attitude and, consequently, their habits and lifestyles. Therefore, the natural outgrowth of behavioral skills plays a key role in any intervention designed to foster an active lifestyle.

Given recent bad habits and societal trends, the investigation of the relationship between an inactive lifestyle, brain functions, and academic performance in school-age children is becoming of fundamental importance. In this context, to clarify the aforementioned issues and based on the available evidence, the European Childhood Obesity Group (ECOG) concluded that moderate-to-vigorous physical activity improves both brain health and academic performance. Therefore, school-based active strategies, such as more frequent physical education lessons, active classes, and active breaks, could be essential in children with overweight/obesity.

Despite this, a better understanding of these implications is absolutely necessary for interventions that provide increased PA with the purpose of achieving a better academic performance. School-based programs that offer increased PA, have the potential to address this problem by reducing the level of obesity and improving academic achievement.

5. Conclusions

In the present systematic review, we briefly analyzed the expansive and ever-growing scientific research related to the impact of PA on cognition and academic achievement.

The findings provided by the present overview, and a significant amount of evidence, suggest that the literature encourages the idea that PA is beneficial for cognitive health and school outcomes among children and adolescents. This could be achieved through several types of PA, carried out in different contexts and with multiple characteristics. Specifically, aerobic and coordinative exercise seem to best promote academic performance. Therefore, our review suggested that PA offers various pathways to improve both physical and mental health over the course of life, through enhancements to the molecular and cellular structure and brain function.

6. Study Limitations and Future Directions

The main limitation of this systematic review was attributable to its search range. The studies used were limited to the last 10 years to provide an up-to-date framework of the present state of the research. Therefore, this short amount of time may have caused studies of significant interest in the national and international panorama to be left out. A further limitation may concern the selection of only longitudinal and experimental studies.

Therefore, although this work provides support for the positive relationship between PA and academic performance, a number of different questions remain unanswered, such as the ability to determine the ideal form, intensity, and timing of PE, how different students' ages might affect PA, and whether similar benefits are documented for students of all sexes, ethnicities, and social backgrounds.

Author Contributions: This article is the result of a study designed and shared between the authors. F.L. and F.T. contributed equally to this work. They contributed intellectually to the manuscript, read the manuscript, and approved the submission. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study was obtained from the included studies and was openly available.

Conflicts of Interest: The authors declare no conflict of interest.

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