PHYSICAL ACTIVITY AND DEVELOPMENT OF EXECUTIVE FUNCTIONS IN DEVELOPMENTAL AGE: A SYSTEMATIC REVIEW

ATTIVITÀ FISICA E SVILUPPO DELLE FUNZIONI ESECUTIVE IN ETÀ EVOLUTIVA: UNA REVISIONE SISTEMATICA

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ABSTRACT
Physical activity (PA) has a positive role in the development of executive functions (EF) in children, improving mental and physical well-being. This systematic review aims to investigate the impact of PA on EF, in developmental age, within different educational environments. This review analysed studies from 2000 to 2025 on children 5-14 years old, following the PRISMA guidelines.
The results confirm the fundamental role of PA in promoting the development of both cognitive and motor skills in children.

L'attività fisica (AF) ha un impatto positivo sullo sviluppo delle funzioni esecutive (FE) nei bambini, migliorando il benessere mentale e fisico. Questa revisione sistematica mira a indagare l'impatto dell'AF sulle FE, in età evolutiva, all'interno di diversi ambienti educativi.
Questa revisione ha analizzato studi dal 2000 al 2025 su bambini di 5-14 anni, seguendo le linea guida PRISMA. I risultati confermano il ruolo fondamentale dell'AF nel promuovere lo sviluppo delle abilità cognitive e motorie nei bambini.

KEYWORDS
Children; cognitive development; educational environment; executive functions; physical activity.
Bambini; sviluppo cognitivo; ambiente educativo; funzioni esecutive; attività fisica

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1. Introduction

In the current scientific literature, more and more attention in educational and developmental research is being paid to the development of executive functions in childhood and adolescence, as, they influence school performance, cognitive, physical, social, and psychological development (Montoya et al., 2019; Diamond 2013). Therefore, early development of executive functions promotes children's physical and cognitive well-being (Watson et al., 2017). Conversely, children who do not have optimal executive function development are at risk for behavioral and emotional problems.

Although, to date, there is no universal definition, which fully describes executive functions, there is a general tendency to consider them as a set of complex cognitive skills that help regulate cognitive, emotional, and motor activity, moreover, they allow one to engage in goal-directed and purposeful behaviours, especially when facing new situations (Theodoraki et al., 2020). Because executive functions are critical to the performance of certain activities such as planning; problem solving; attention control; and self-regulation; they are generally regarded as a multifaceted structure, rather than a unitary construct.

In the literature, when discussing executive functions, it is usual to refer to a model consisting of (Diamond, 2013): inhibition, working memory and cognitive flexibility. Inhibition is the ability through which attention, behaviour and emotions can be controlled, leaving out inappropriate actions to take the best action. Working memory, on the other hand, enables short-term storage and management of information for the performance of effective actions. It helps children reorganize information, translate instructions or incorporate new information into action plans. Finally, cognitive flexibility is the ability to change the focus of attention according to the demands of the task and to adopt different strategies for problem solving, adapting to new or unexpected situations. It also enables creative thinking, approaching circumstances from alternative perspectives and seizing unexpected opportunities.

Best et al. (2009) in their study reveal that the development of executive functions in children occurs at different times and each one follows a certain developmental process, in particular, there is rapid development during the elementary school period, however, during adolescence there is a slowdown. Specifically, inhibition is the first ability that develops, followed, by working memory and cognitive flexibility. As just highlighted, during early childhood there is rapid development of

executive functions. At this stage, lived experiences become critically important, as the brain is highly flexible, making this period particularly favourable for promoting effective interventions (Zelazo & Carlson, 2012).

Furthermore, it is important to note that executive functions depend on the prefrontal cortex, which plays a crucial role in the development of fundamental cognitive abilities (Garon et al., 2008). A series of changes occur in the prefrontal cortex between the ages of 3 and 5 that affect the development of executive functions. Since the brain during this period is endowed with particular plasticity, if any difficulties are present, it is necessary to address them, rather than neglect them, because they may worsen in later years (D'Anna et al., 2024). Unlike the other areas of the brain, the prefrontal cortex and its connections, cortical and subcortical, develop slowly and during rapid developmental stages are sensitive to environmental stimuli (Kolb et al., 2012). This aspect hints at how executive functions are enhanced as the prefrontal cortex develops and, in addition, this development may be fostered or limited by the child's lived experiences. Recent studies in the field of neuroscience highlight how physical activity can contribute to improved executive functions, especially in children and adolescents (Diamond, 2012; Kolovelonis & Goudas, 2023), as it usually involves not only physical but also cognitive involvement. When we talk about physical activity, we tend to refer to any muscular movement that requires energy expenditure. Physical activity can change in format (from simple exercises to complex programs), intensity (measured by individual maximum load), and duration (single session or program over several weeks) (Barenberg et al., 2011).

Among the benefits associated with performing physical activity, one should not overlook, its influence on individual characteristics such as personality and soft skills. In addition, physical activity promotes plasticity of gray and white matter structures (Xiong, et al., 2018; Weinstein, et al., 2012), optimizes brain activation during the performance of specific tasks (Chaddock-Heyman, et al., 2013), and enhances the brain's functional networks (Meijer, et al., 2022), thus contributing to the improvement of executive functions in children and adolescents.

According to what has just been pointed out, physical activity is an effective strategy for stimulating executive functions, but as can be seen from the studies by Kolovelonis & Goudas (2023); Pesce et al. (2013), cognitively stimulating physical activity is also particularly suitable for enhancing executive functions (Vazou et al., 2019; Pesce 2012; Schmidt et al., 2015).

The concept of cognitive engagement refers to the levels of attention and mental effort required to perform an activity. According to Schmidt et al. (2015) and Vazou et al. (2019), physical activities that require high cognitive engagement produce more significant effects on executive functions than activities that involve automatic and repetitive movements. In fact, activities with cognitive involvement, cause students to find themselves in unpredictable situations and to find the solution they have to call on their problem solving, decision making and other life skills that are useful not only in the school context, but also in dealing with daily life challenges. Importantly, the effects of physical activity on improving attention, executive functions, and academic performance in children depends not only on the duration but also on the type of activity proposed (De Greeff et al., 2018).

The international literature highlights not only the benefits of physical activity as such, but also the importance of the ways in which it is practiced. In particular, activities performed in groups appear to enhance the positive effects of exercise on cognitive function, as they involve the use of complex cognitive processes related to collaboration with others and the use of flexible strategies to adapt to changing tasks (Davis et al., 2007). Group activities also promote children's social involvement and provide valuable learning opportunities through peer interaction (Eidsvåg & Rosell, 2021).

In light of the foregoing, physical activity, especially when enriched with cognitive components (Coppola et al., 2024), would seem to favour a significant improvement in executive functions in children compared to simple physical activity or sedentary activities; the variable related to the dynamic and unpredictable learning environments in different educational settings may also affect the extent of these benefits and thus the achievement of psychophysical well-being. For this reason, when designing educational and training interventions, it is important to understand how the different variables involved can foster the overall development of the person and thus the acquisition of skills and competencies. The present systematic review aims to analyse the international scientific literature and in particular experimental studies investigating the relationship between physical activity and executive functions to study and compare different intervention methodologies to understand the effects of physical activity, systematizing it by age periods, type of intervention and executive functions involved.

2. Materials and methods

2.1 Literature Search

Research was conducted in the databases: Google Scholar, PubMed, Scopus, Web of Science; to identify potentially relevant articles in accordance with PRISMA guidelines (Moher et al. 2009). The research was carried out up to the latest available date (last research April 2025), with the aim of synthesizing the available knowledge on the relationship between physical activity and executive functions in developmental age by analysing studies published between 2000 and 2025.
The following keywords and combinations of them were included in the different databases: adolescents, children, cognitive development, cognitive flexibility, cognitive functions, developmental age, executive functions, inhibition, physical activity, working memory.
The strings used are shown here: [(executive functions) or (inhibition) or (working memory) or (cognitive flexibility) and (developmental age) and (children) and (physical activity)], [(executive functions) or (cognitive functions) and (cognitive development) and (adolescents)].

2.2 Study selection and screening process

The review was chosen as a method to identify and summarize the existing scientific literature on a complex and multidimensional topic, highlighting the main aspects related to the topic being considered. Specifically, to be included in this literature review, studies had to meet the following criteria:

- Type of studies: experimental or quasi-experimental
- Participants: developmental age (5-14 years)
- Interventions: physical activity and/or cognitive activity as a tool that stimulates executive functions
- Results: effects of physical activity on executive functions

Instead, the following were excluded: literature reviews; studies whose participants were younger than 5 years or older than 14 years; studies that had no effect on executive functions.

2.3. Study Procedures

The research was conducted by two reviewers, who selected the studies according to the predefined criteria by evaluating the titles and abstracts. Then, all authors independently studied the selected abstracts to determine their final eligibility based on the exclusion and inclusion criteria. In addition, the references of the selected studies were analysed to find additional studies for inclusion in this literature review. Overall, the results show a degree of consistency in detecting positive effects of physical activity on executive functions, with some variation attributable to methodological differences or sample characteristics.

A methodological limitation might be the absence of an active control group (Liu et al., 2024; Wimbarti et al., 2020; Jäger et al., 2015). These factors represent potential sources of bias and may limit the generalizability of the results.

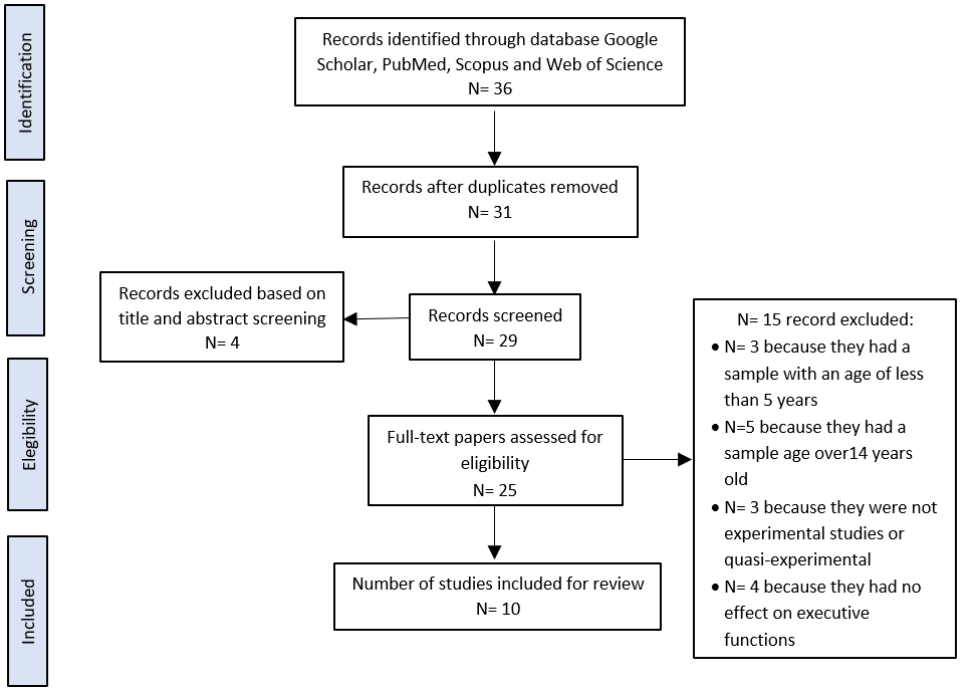
For each included study, information was considered regarding: the source (authors and year of publication), sample characteristics (number of participants and mean age), research purpose, methodological approach, type of physical activity examined, study duration, and main findings that emerged.

3. Results

Scheme 1 represents the literature review process, which consisted of several steps. Initially, (36) articles were identified by searching the Google Scholar, PubMed, Scopus, and Web of Science databases. After removal of duplicates, the number of articles was reduced to (31). Of these, (29) articles were screened based on title and abstract, which resulted in the exclusion of (4) studies. After this screening, (25) articles were subjected to a more thorough evaluation, and (10) were considered suitable for full-text analysis. However, (15) articles were excluded for the following reasons:

- 3 articles included a sample with an age of less than 5 years
- 5 articles included a sample with an age older than14 years
- 3 articles were nonexperimental or quasi-experimental
- 4 articles had no effect on cognitive function

Finally, the total number of studies included in the review was 10.



scheme 1**.** Flowchart

Data from each study included in this survey were processed and included in Table 1. Specifically, for each study, the table includes information on the source (author, year of publication), sample (sample size, mean age of participants), objective, methodology, type of physical activity, duration and main results.

Table 1. Summary of the literature analysis.

AUTHORS	**PARTICIPANTS**	**AVERAGE AGE**	**OBJECTIVE**	**METHODOLOGY**	**TYPE OF PHYSICAL ACTIVITY**	**DURATION**	**RESULTS**
Jäger et al. 2015	219	11	To examine the effects of acute physical activity interventions on the three dimensions of executive functions, in real-	Children were randomly assigned to one of four experimental conditions: (1) physical games (PA with cognitive engagement), (2) aerobic exercise (PA	Aerobic exercises	20 minutes	Children with greater physical fitness and/or higher academic achievement, however, achieved improvements in executive functions

			world settings	without cognitive engagement), (3) cognitive games (sedentary with cognitive engagement), and (4) control condition (sedentary without cognitive engagement)			
Cooper et al. 2018	39	12	The aim of the present study was to examine the effect of physical activity on cognitive function in adolescents	Participants completed two conditions: Exercise trial (60 minutes of game-based activity) and Rest trial (time spent sitting at rest).	Basket	60 minutes	Game-based activities improved executive function especially in trained adolescents
Wimbarti et al. 2020	132	6	To examine the effect of exercise in improving components of executive functions in preschool children	They were divided into three groups: experimental group 1 (complex physical activity with cognitive involvement); experimental group 2 (simple physical activity without cognitive involvement); control groups (no treatment).	Simple activity (running, jumping) vs. complex (with obstacles and rules)	2 times a week for 4 weeks	Significant improvements in inhibition and working memory in the complex activity group
Williams et al. 2020	36	12.6	The purpose of the present	36 adolescents participated in two	soccer	60 minutes per session	Significant improvements emerged, for working

			study was to investigate the effect of an acute outdoor soccer game on information processing, inhibitory control and working memory and working memory in adolescents.	conditions: 60 minutes of soccer and 60 minutes of rest		(2 separate 7-day sessions)	memory, in students trained
Zhang et al. 2020	63	5.5	To study the effect of an acute moderate-to-vigorous intensity physical activity session on executive function, considering habitual PA level.	Children were divided into two groups according to their usual level of physical activity (high or low)	Aerobic workout and age-appropriate games (relay, group dance, squats)	25 minutes	Improvements in inhibition ability in active children
Jia et al. 2021	40	5.5	This study investigated the effects of different types of exercise on preschoolers' cognitive abilities.	Participants were divided into two groups: one group did specific physical activity; the other did simple physical activity	Walking, running, jumping, climbing, throwing	60 minutes, 3 times a week for 12 weeks	Significant improvement in cognitive ability and experimental group.
Fernandes et al. 2022	67	10.3	The aim of the study was to evaluate the effect of Capoeira on executive	Participants were randomly assigned to Capoeira teaching or control group	Typical Capoeira movements	4 months, with 60-minute sessions, three times a week	A positive correlation was found between improvement in executive functions and the

			functions in children.				number of Capoeira classes attended
Kolovelonis & Goudas 2023	144	9,94	To investigate the effects of cognitively demanding physical activity games on students' executive functions and situational interest in physical education.	Participants were randomly assigned: Group 1 (cognitively demanding physical activities); Group 2 (soccer skills); Group 3 (athletics skills); Group 4 (control)	Hop, Pop, and Tag: Crazy Traffic Lights; Maps	45 minutes	Significant improvement in executive functions in cognitively stimulating tasks
Zhong et al. 2024	80	11	Exploring the relationship between physical training and inhibitory control	The experimental group underwent physical training (volleyball), whereas the control group did not undergo any training and continued with their daily activities.	Mixed training, consisting of medium-intensity volleyball skills training combined with practical application in group games and structured competitive scenarios	60 minutes, three times a week for 12 weeks	Significant improvements in inhibitory control in the experimental group.
Liu et al. 2024	60	9.5	To investigate the effects of two different rope exercise modes (HIIT high-intensity interval	Children were divided into HIIT, MICT and control (rest without exercise).	HIIT: rapid high intensity jumping. MICT: continuous moderate jumping.	10 minutes	Both HIIT and MICT improve working memory and inhibitory control, HIIT greater effect on attention.

			training and MICT moderate-intensity continuous training) on cognitive function in 9- to 10-year-old children.				

The objective of the present systematic review is to analyse the international scientific literature and experimental and quasi-experimental studies investigating the relationship between physical activity and executive functions to study and compare different intervention methodologies to understand the effects of physical activity, systematizing it by age periods, type of intervention and executive functions involved.

The studies reported, emphasize the positive influence of physical activity on executive functions, in the developmental age.

To make the exposition of the results presented in this review clearer, we have chosen to organize them by referring to the main stages of developmental age. In particular, the following will be considered: second childhood, which includes children aged 3 to 5-6 years (Jia et al., 2021; Zhang et al., 2020; Wimbarti et al., 2020); boyhood, which ranges from 6 to 10 years (Liu et al, 2024; Kolovelonis & Goudas, 2023); and finally adolescence, which extends roughly from ages 10 to 20 (Jäger et al., 2015; Zhong et al., 2024; Fernandes et al., 2022; Williams et al., 2020; Cooper et al., 2018).

Specifically, for second childhood, Zhang et al. (2020) investigated the effects of an acute session of moderate-vigorous physical activity (MVPA) on the executive functions of 63 preschoolers, differentiated by habitual activity level. The activity consisted of 25 minutes of aerobic games; functions were assessed by the Corsi Block-Tapping Task, the Dimensional Change Card Sort, and the Day-Night Stroop Task. Results show improvements in inhibition in habitually more active children. In support, Wimbarti et al. (2020) compared the effect of complex versus simple motor tasks on 132 preschool children. Through two weekly sessions for four weeks, and using standardized tests (Spatial Conflict Arrow Test, Pick the Picture

Test), they showed improvements in inhibition and working memory in the group engaged in complex activities. In line with these findings, Jia et al. (2021) evaluated the effects of a 12-week motor exercise program on the cognition of preschoolers. Through the Wechsler Preschool and Primary Scale of Intelligence, significant improvements in cognitive performance were found in the experimental group compared with the control group.

Liu et al. (2024) and Kolovelonis & Goudas (2023), on the other hand, focused on the effects of physical activity on executive functions during childhood. The study by Kolovelonis and Goudas (2023) used a quasi-experimental design with four groups to evaluate the effect of different physical activities on executive functions and situational interest. The results obtained through the Design Fluency Test showed that students involved in cognitively demanding physical activity games (Group 1) achieved significant improvements in executive functions, compared with those engaged in soccer skills, with the exception of Group 3, engaged in athletic activities. The benefits on executive functions were also confirmed when the cognitively challenging activities were offered later to the control group. Similarly, Liu et al. (2024) studied the effect of jumping rope exercises at different intensities (HIIT vs MICT) on 60 9- to 10-year-old children. Comparing pre- and post-intervention using Digit Span Test, Attention Network Test and Stroop Color-Word Test, they observed improvements in working memory and inhibitory control in both groups, with superior benefits for HIIT.

Finally, the transition from childhood to early adulthood, adolescence was explored in depth by Jäger et al. (2015), who evaluated 219 children by subjecting them to different activity conditions (cognitive PA, aerobic, sedentary cognitive games, control). Through tests of updating (n-back), inhibition (Flanker) and shifting, significant improvements in executive functions emerged only in children with high physical fitness or school performance. Zhong et al. (2024) examined the effect of 12 weeks of volleyball training on 80 adolescents. Using the Flanker Task and fNIRS to monitor prefrontal activity, they found a significant improvement in inhibitory control in the experimental group compared with the control group. The adolescent period was also studied by Fernandes et al. (2022), whose sample consisted of 67 children (8-13 years old) engaged in 4 months of Capoeira. The scholars assessed executive functions through the Stroop test and subtests of the Wechsler Intelligence Scale for Children, showing a positive relationship between number of classes attended and improvement in executive functions, as well as progress in hand-eye coordination. Williams et al. (2020) analysed the effects of an outdoor

soccer game, on information processing, inhibitory control and working memory in adolescents. Through the Stroop Test and the Sternberg Paradigm, an improvement in working memory was observed only in adolescents with high levels of physical activity. Cooper et al. (2018) evaluated 39 adolescents by subjecting them to a basketball game-based activity compared to a resting condition. By measuring executive functions with the Stroop Test, Sternberg Paradigm, Trail Making Test and d2 Test of Attention, improvements in executive functions were found especially in trained adolescents.

4. Discussion

According to the aim of this systematic literature review, after delving into the benefits of physical activity on executive functions with respect to age periods, it is also appropriate to refer to the executive functions involved.

The results of studies by Cooper et al. (2018), Kolovelonis & Goudas (2023), Fernandes et al. (2022), Jäger et al. (2015), and Jia et al. (2021) support the effectiveness of physical activity on the three components of executive functions. The intervention by Zhong et al. (2024) had particularly significant effects on inhibition ability. From the studies by Liu, et al. (2024) and Wimbarti et al. (2020), on the other hand, there were improvements to both working memory and inhibition. In the case of the study by Williams et al. (2020) only significant improvements were recorded for working memory.

As evidenced by the findings from this review, not all the proposed physical activity interventions benefited the three components of executive functions-working memory, flexibility, and inhibition-but only some of them. Suggesting that the effectiveness of the intervention might be related to the type of activity proposed, duration, and intensity.

Shifting the focus of the discussion to the type of protocol implemented Kolovelonis & Goudas (2023), Wimbarti et al. (2020) Jäger et al. (2015), proposed cognitively engaging activities, which as stated by Pesce C. et al. (2017) and Pesce C. et al. (2013) require greater coordinative complexity and cognitive demands, effective for the development of students' physical and motor coordination and executive functions. Also, Jäger et al. (2014) in their study observed an improvement in inhibition, for the experimental group that performed cognitively stimulating physical activity, compared to the control group.

In addition, considering the activities implemented in some of the studies included in this review, it is interesting to consider the influence of open and closed skills on cognitive function. Specifically, in the studies by Cooper et al. (2018), Zhong et al. (2024), Williams et al. (2020), they do to activities such as: basketball, volleyball and soccer. These are, therefore, open skills that as also supported by Gu et al., (2019) have greater effects on improving cognitive function than closed skills. In open skills the environment is variable and dynamic, in this context it is difficult to predict the actions of the opponent, so the athlete must adapt his motor response to the situation that arises. Closed skills, on the other hand, occur in a stable and predictable environment, therefore, the motor response can be predetermined. In reference to open skills, Alesi et al. (2016) in their study found that students who played football for six months improved their coordination skills and executive functions, in fact this type of activity requires coordination, balance, but also concentration and problem resolution leading to psychophysical improvements.

When designing physical activity interventions, in order to achieve improvements in executive functions, it is essential to propose activities that fall within the 'zone of proximal development' (Vygotsky, 1978), that is, that are slightly above children's current level of competence. This maintains high levels of attention, motivation and interest.

In the current scientific literature, more and more attention is being paid to the positive relationship between to physical activity, cognitive functions and students' academic performance (Schmidt et al., 2017; Rigoli et al., 2012; Van Der Niet et al., 2014). In fact, executive functions, appear to mediate the response between physical activity and school performance, suggesting that increased physical activitynot only improves motor skills, but also has a positive effect on executive functions, which in turn positively influence school performance. Thus, integrating physical activity appropriately, within the school day could be an effective opportunity, not only for psychological and physical well-being, but also for school success (D'Anna et al., 2024). In this regard, Valentini and Gennari (2024) highlight the importance of considering executive functions as a fundamental basis for the development of skills related to planning, reasoning, and problem solving. Indeed, these functions positively influence knowledge acquisition, reading and numeracy skills, thus helping to promote effective and quality learning (Diamond & Lee, 2011; Pesce, 2012).

Although the overall results support the effectiveness of physical activity on the development of executive functions, there remain some limitations, related to the

number of studies included; moreover, through the combination of keywords different from those used, the research could be enriched, allowing for a broader and deeper exploration of the relevant literature.

Conclusions

Considering the findings through this systematic review of the literature designed to investigate the effects of physical activity on executive functions in developmental age, the results obtained, provide further supporting evidence that physical activity, especially cognitively stimulating physical activity, provides benefits to executive functions. Such improvements, as highlighted repeatedly, are also positively reflected on learning processes and school performance.
The implementation of activities that include cognitive challenges can be considered an effective strategy to promote the current trend of designing physical activity and physical education programs that are both motor and cognitively stimulating, thus contributing to students' overall well-being and development.
Future research could consider longitudinal studies, then analyse the effects of long-term physical activity on executive functions and correlate this with school performance. In addition, it would be interesting, to investigate the influence of educational climate.

Author contributions

All authors collaborated in the design and regular review of the manuscript. C.D. designed the methodology, wrote the discussion and conclusion paragraphs, and supervised the study. C.M. wrote the introduction paragraph, the abstract and methodology. E.P. and P.F. contributed to the literature research, data collection and edited the translation. All authors have read and agreed to the published version of the manuscript.

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