COGNITIVE FUNCTIONING AND CLASSROOM-BASED PHYSICAL ACTIVITY

FUNZIONI COGNITIVE E ATTIVITA' FISICA IN CLASSE

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ABSTRACT
Physical activity has been shown to have numerous cognitive benefits for youths. In particular, by incorporating regular physical activity into curricular routines, students can reap these cognitive benefits, which can have a positive impact on their math performance. Therefore, aim of the present work was to investigate how a classroom-based physical activity intervention could affect mathematics performance both in students with mathematics learning disabilities and who do not have any specific learning disabilities. Participants were 104 students attending the first year of high school. At baseline and after intervention, a battery of standardized motor tests and the AC-MT 11-14 test was administrated. In comparison to the control, the intervention group showed significant improvements in comprehension and production, arithmetic reasoning and problem solving, as well as in physical fitness. No significant changes were found in the control group. The findings of this study indicated that integrating physical activity with mathematics classes has stronger effects on mathematics performance than traditional lessons.

È stato dimostrato che l'attività fisica ha numerosi benefici cognitivi per i giovani. In particolare, integrando l'attività fisica nelle routine curricolari, gli studenti possono migliorare le proprie prestazioni matematiche. Pertanto, lo scopo del presente lavoro è stato quello di indagare come un intervento di attività fisica in classe possa influenzare le prestazioni matematiche sia in studenti con difficoltà di apprendimento matematico che in quelli che non hanno disturbi specifici dell'apprendimento. I partecipanti erano 104 studenti che frequentavano il primo anno di scuola secondaria di secondo grado. Al basale e dopo l'intervento, è stata somministrata una batteria di test motori standardizzati e il test AC-MT 11-14. Rispetto al gruppo di controllo, il gruppo di intervento ha mostrato miglioramenti significativi nella comprensione e nella produzione, nel ragionamento aritmetico e nella risoluzione dei problemi, nonché nella forma fisica. Non sono stati riscontrati cambiamenti significativi nel gruppo di controllo. I risultati di questo studio hanno indicato che l'integrazione dell'attività fisica con le lezioni di matematica ha effetti sulle prestazioni matematiche rispetto alle lezioni tradizionali.

KEYWORDS
Academic achievement; physical activity; learning disabilities.
Successo scolastico; attività fisica; disabilità di apprendimento.

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1. Introduction

Effective educational strategies are known to have a considerable impact on students' readiness to attain their academic goals, particularly in the realm of mathematical proficiency. By employing high-quality educational strategies, educators can effectively support students in developing mathematical competence and achieving their academic goals. These strategies not only help students succeed in mathematics but also equip them with valuable skills and knowledge that are essential for lifelong learning and success (Zhang, Zhao, & Kong, 2019). Over the last decade, there has been significant research focused on children's mathematical disabilities. This increased attention is crucial because poorly developed mathematical competencies can have profound consequences for individuals in various aspects of life, including employment and day-to-day living in today's modern world (König et al., 2021). Research in this area have examined various educational strategies and interventions designed to support children with mathematical disabilities. This research helps educators implement evidence-based practices that are effective in improving mathematical skills and outcomes for these students (Chang, & Beilock, 2016).

Mathematical competence is a fundamental skill that underpins success in many academic domains, including science, technology, engineering, and mathematics (STEM) fields. Research on mathematical disabilities highlights the impact of these difficulties on overall academic achievement and underscores the importance of addressing them to ensure educational success (Verschaffel, Schukajlow, Star, & Van Dooren, 2020). The mathematical field encompasses various domains that are partially autonomous and distinct. In fact, a crucial differentiation arises in relation to disorders in mathematical computation and disorders in arithmetic problem solving and reasoning skills (Schneider et al., 2018). These disorders are associated with a condition that affects multiple functions, including working memory, attention, and metacognition. Individuals facing challenges in arithmetic problem solving and arithmetic reasoning skills may possess adequate abilities in handling numbers and calculation processes, yet they encounter difficulties in recognizing and incorporating verbal information, visuospatial representation, and planning the necessary procedures for problem-solving. Arithmetic problem-solving and reasoning necessitate a range of intricate cognitive skills and abilities (Schneider et al., 2017), such as (i) Coding, defined as the capacity to transform the information extracted from the text into an internal representation. Language proficiency and semantic memory play a role in facilitating this process. Nonetheless, cognitive integration is essential to amalgamate these steps; (ii) Solving, involving the retrieval of necessary information from memory to arrive at a final solution; (iii) Forecasting, entailing the prediction of whether the problem is solvable; (iv) Planning, encompassing the creation of a plan; (v) Monitoring, enabling the control of the process; (vi) Appraisal, signifying the evaluation of the end result.

One possible method for enhancing the development of arithmetic problem-solving skills and arithmetic reasoning is by means of educational strategies that prioritize experience and critical thinking. They help students develop the ability to analyze complex problems, think creatively, and apply mathematical concepts in novel situations (Ukobizaba, Nizeyimana, & Mukuka, 2021). Physical activity seems to be a promising way to immediately enhance youths' cognitive performance. Encouraging youths to engage in regular physical activity can be a powerful way to support their cognitive development and academic success. Incorporating regular physical activity into scholastic daily routines can have profound effects on cognitive performance in youths, leading to improvements in academic achievement, mental well-being, and overall quality of life. Engaging in physical activity has been associated with enhanced attention and focus, allowing youths to concentrate better on academic tasks and daily activities.

Specifically, a growing body of literature highlights that classroom-based physical activity breaks positively impact math performance (Sneck et al., 2019). Classroom-based physical activity refers to incorporating physical activity break into the school day within the classroom setting or in integrating it with learning activities. These activities are designed to promote movement, improve physical fitness, support health and well-being among students, and enhance learning and cognitive performance. Teachers may incorporate short movement breaks between lessons or include physical activity-based games or challenges that reinforce academic concepts (Vazou, & Skrade, 2017). In addition, classroom-based physical activity promotes a positive classroom climate by creating a dynamic and inclusive learning environment where students feel supported, engaged, and motivated to participate. It also fosters a sense of community and teamwork among students.

Several studies have illustrated the impact of Classroom-based physical activity on various aspects of learning, ranging from basic cognitive processes to more intricate tasks like text comprehension and problem-solving (Donnelly, & Lambourne, 2011). The influence of classroom-based physical activity on academic outcomes among schoolchildren can be facilitated by a multitude of mediating factors. Recent research suggests that classroom-based physical activity can induce structural and functional modifications in the brain, affecting processes like energy metabolism and synaptic plasticity, thereby potentially enhancing children's development through favorable effects on brain systems crucial for cognitive functions and behavioral tendencies (Mavilidi, & Vazou, 2021). Additionally, substantial evidence supports the notion that integrating classroom-based physical activity into the school day can have a positive influence on children's cognitive and behavioral engagement in school, attention span, time spent on tasks, and executive functions, all of which are closely linked to academic success in subjects like reading and mathematics. Another mediating factor worth considering is the relationship between children's motor development and cognitive learning, highlighting how classroom-based physical activity could impact academic performance. Furthermore, several studies have indicated that various cognitive skills, such as visuospatial abilities, rapid automatized naming, processing speed, and memory skills, can be influenced by physical activities involving cognitively stimulating tasks (Syväoja et al., 2021).

Considerable research has been devoted to examining physical activity interventions within educational settings (Vetter, Orr, O'Dwyer, & O'Connor, 2020). However, there is a lack of investigation on the potential impact of a classroom-based physical activity program on arithmetic problem-solving skills and reasoning abilities. Hence, the current investigation endeavored to determine whether the implementation of classroom-based physical activity can help to improve math performance and have a positive effect on student attitudes toward math.

2. Materials and Methods

2.1. Study design

This is a randomized controlled trial in which a conveniently selected sample of students (attending the first year) were randomly allocated to intervention and control groups. The investigation was conducted within a high school located in the South of Italy. The experimental (n = 52) and control (n = 52) group participated either a Classroom-based physical activity intervention integrated within math classes or regular math lessons. Both interventions entailed two sessions of classroom-based physical activity per week, each lasting 60 minutes and taking place during regular school hours. The assessments were conducted both prior to and upon completion of the intervention programs.

2.2. Participants

A total of 104 students, aged between 13 and 15 years (mean age = 12.85, standard deviation = 0.36), were selected as a convenient sample for the research endeavor. In this study, enrollment was based on voluntary participation, with inclusion criteria encompassing all third-grade students. The established criteria for inclusion aimed at forming a sample that could adequately meet the research requirements: students attending first year, students from the designated educational institutions, individuals in good health, competent in completing an exercise regimen, and willing to refrain from engaging in other physical activities during the study period. An a priori power analysis was conducted with a specified type I error rate of 0.05 and a type II error rate of 0.05, which corresponds to a statistical power of 95%. The analysis indicated that a total of 50 participants would be adequate for detecting medium "Time x Group" interaction effects ($f = 0.25$). In order to accommodate potential drop-outs, larger sample sizes were recruited.

As per the specified inclusion criteria, a total of 120 individuals were extended invitations to partake in the investigation. Out of this group, 16 individuals opted out citing personal reasons; however, 104 subjects consented to engage in the research endeavor and underwent the initial measurements. Subsequently, the conclusive sample size was established at 104 participants, who were duly matched and arbitrarily allocated to one of the two treatment conditions. The Experimental Group ($n = 52$) was comprised of 32 male and 20 female individuals, whereas the Control Group ($n = 52$) consisted of 35 male and 17 female participants. Written consents were obtained from all parents of the participants, with clear notification provided regarding their ability to retract their consent at any juncture. This investigation was executed in compliance with the principles delineated in the Declaration of Helsinki.

2.3. Procedures

The intervention program was conducted within the confines of the school gymnasium on regular school days. Evaluation of standardized motor assessment tests and Math performance was carried out before and after the intervention period to ascertain the initial level of the participants and to identify any changes in comparison to the baseline.

Each participant undertook the tests simultaneously each day under identical experimental conditions. The students underwent individual assessments, with each task being thoroughly explained before commencement. Measures were taken to ensure that the children were uninformed about the study's objectives or the experimental setup, in order to mitigate any potential bias that could compromise the integrity of the data. Participants were advised to don appropriate sportswear to minimize inconsistencies in the testing process and were instructed to refrain from excessive physical activity 24 hours prior to each testing session. The measurements for the assessments and both intervention programs were administered, monitored, and executed by two adept Physical Education instructors accredited by the Italian Ministry of Education.

2.4. Measures

2.4.1. Motor tests

The evaluation tests for physical fitness comprised four measurements: the Standing long jump test assesses the lower-body horizontal explosiveness, the

Push-up test measures upper body strength and endurance, and the Sit and reach test evaluates the extensibility of the hamstring muscles and lower back.
These assessments were selected due to their ease of implementation, minimal time requirement, and basic equipment needs [42], making them particularly suitable for educational settings. Moreover, these tests were conducted both pre- and post-intervention programs.

2.4.2. AC-MT 11-14 Test

The AC-MT 11-14 is a thoroughly validated assessment tool that enables a standardized and thorough evaluation of arithmetic problem-solving and arithmetic reasoning skills. This test comprises two distinct sections: the Collective part on numbers and calculation, and Problem solving. These sections necessitate collective administration and evaluate proficiency in numbers, arithmetic reasoning, and problem-solving. The initial section is comprised of 8 subtests: performing operations, solving arithmetic expressions, identifying the largest value, converting words into numbers, completing numerical series, transcribing words into numbers, making approximate calculations, as well as assessing knowledge of facts, procedures, and principles. Within this section, three overarching variables can be identified, namely written calculation, comprehension and production, and arithmetic reasoning.
The administration of the test requires approximately 60 minutes for the initial section and 30 minutes for the second section, which includes instruction and practice components. The scoring mechanism awards 1 point for each correct response and 0 points for each incorrect response.

2.5. Training intervention

The exercise training intervention was structured in the following manner: an initial segment focused on enhancing flexibility (3 minutes), a central component of moderate-to-vigorous aerobic exercise (15 minutes), and finally a cool-down phase (2 minutes) aimed at maintaining a safe heart rate. The warm-up routine comprised activities such as marching in place, walking jacks, Knee to chest, Heel digs, arm circles, shoulder rolls, Knee lifts, Butt kicks, lunges, Side steps, and High knees. Conversely, the cool-down phase incorporated stationary exercises like neck stretch, behind-head tricep stretch, standing hip rotation, Hamstring stretch, Hip flexor stretch, side stretch, and butterfly stretch.
Each active break was strategically integrated to take place both between and within science classes, during which a nutritional education program was implemented.

A standard session of an active classroom intervention encompassed: i) active breaks interspersed between and within educational tasks; ii) learning activities incorporating physical movement; iii) utilizing benches, standing desks, floor spaces, or a blend of these to facilitate movement between different work stations; - engaging in learning activities outdoors.

Statistical Analysis

Statistical analyses of the results were performed utilizing IBM SPSS Statistics, version 26.0 (2019 SPSS Inc., IBM Company). The data were displayed as group mean (M) values and standard deviations (SD), and assessments were made regarding the homogeneity of variances through Levene's test. To examine the normality of all variables, the Shapiro-Wilk test was employed. Initially, an independent sample t-test was utilized to identify any disparities between groups at the baseline, followed by a two-way ANOVA (experimental/control group) x time (pre/post-intervention) with repeated measures on the time dimension, to evaluate the impact of the intervention on all variables under scrutiny. Subsequent to establishing significance in the "Group x Time" interactions, specific post hoc tests (paired t-test) for each group were conducted to ascertain meaningful comparisons. Partial eta squared (η2p) was employed to gauge the effect size within each group, with delineations for small ($\eta2p < 0.06$), medium ($0.06 \leq \eta2p < 0.14$), and large ($\eta2p \geq 0.14$) effects. Additionally, Cohen's d was calculated for each analysis with benchmarks indicating small ($d = 0.20$), medium ($d = 0.50$), and large ($d = 0.80$) effect sizes. The threshold for statistical significance was defined as $p \leq 0.05$.

3. Results

The two cohorts of subjects were administered the designated treatment protocols. There was no notable contrast between the experimental and control clusters in terms of age, anthropometric traits, or educational attainment at the outset ($p > 0.05$).

3.1. Motor tests

A two-factor repeated measures ANOVA found a significant 'Time x Group' interaction for the standing long jump test ($F_{1,102} = 27.60$, $p < 0.001$, $\eta^2_p = 0.72$, large effect size), Push-up test ($F_{1,102} = 345.58$, $p < 0.001$, $\eta^2_p = 0.77$, large effect size), and Sit and reach test ($F_{1,102} = 377.71$, $p < 0.001$, $\eta^2_p = 0.78$, large effect size). Post hoc analysis revealed that the experimental group made significant increase from pre- to post-test in standing long jump test ($t = 4.36$, $p < 0.001$, $d = 0.81$, large effect size), and an increase in Push-up test ($t = 8.63$, $p < 0.001$, $d = 0.84$, large effect size), and sit and reach test ($t = 4.53$, $p < 0.001$, $d = 0.89$, large effect size). No significant changes were found for the control group ($p > 0.05$).

3.2. AC-MT 11-16 Test

Statistical analysis indicated a significant 'Time x Group' interaction for the AC-MT 11-16 Test across three out of four macro-variables, specifically Comprehension and production ($F1,_{102} = 211.60$, $p < 0.001$, $\eta 2p = 0.67$, large effect size), Arithmetic reasoning ($F1,_{102} = 114.97$, $p < 0.001$, $\eta 2p = 0.54$, large effect size), and Problem solving ($F1,_{102} = 143.94$, $p < 0.001$, $\eta 2p = 0.59$, large effect size). Subsequent post-hoc analysis unveiled a noteworthy enhancement in the experimental group's performance concerning Comprehension and production ($t = 14.90$, $p < 0.001$, $d = 2.06$, large effect size), Arithmetic reasoning ($t = 19.80$, $p < 0.001$, $d = 2.74$, large effect size), and Problem solving ($t = 10.61$, $p < 0.001$, $d = 1.47$, large effect size). Conversely, no statistically significant alterations were observed within the control group ($p > 0.05$).

4. Discussion

The aim of this study was to assess the efficacy of a classroom-based physical activity intervention on arithmetic problem-solving and reasoning skills in first-year high school students, in comparison to traditional instructional methods. This impact was more pronounced in the classroom-based physical activity group than in the control group, where conventional teaching methods involving regular math lessons lacking physical activities engagement were utilized.

Within the scope of this investigation, the results demonstrate that the benefits were more significant in the classroom-based physical activity cohort, which engaged in physical activities integrated with math. Conversely, the conventional classes, which did not involve any practical exercises, proved to be less effective in achieving outcomes consistent with the stated objectives.

This investigation appears to align with earlier scholarly works that assert that physical activity integrated with cognitive engagement yields positive impacts on academic achievements. Decades of research have shown a positive relationship between physical activity and cognitive function in children. This research field has been aptly summarized in a review by Tomporowski and Ellis (1986) and more recently by Sibley and Etnier (2003). Studies done by Sibley and Etnier have shown that physical activity has a small but significant effect on cognitive ability. One study conducted by Reed, Einstein, Hahn, and Hooker (2010) has shown that there is an increase in mathematics performance in children immediately after engaging in physical activity. This study is one of the first to explore the connection between exercise and academic achievement in children and its result is in line with an expanding field of research using acute bouts of exercise to facilitate learning. The results of Reed et al. along with the broader field of research mentioned above serve as a platform to create a linkage between the promotion of physical activity and academic achievement in the classroom.

Data from brain research also suggests that an enriched environment and activities requiring complex movements can stimulate cognitive development. One hypothesis that explains the effects of physical activity on cognitive function is that movement provides an enriched environment complemented by complex activities, which in turn enhances learning (Haverkamp et al., 2020).

There are various physiological mechanisms by which physical activity may improve cognitive function. It is believed that physical activity can lead to increased cerebral blood flow and subsequent increase in brain volume (Aguayo, Román, Sánchez, & Vallejo, 2022). This occurs via vascularization and is known to occur across the lifespan. Changes in brain growth factor also occur and increases in cognitive neurotrophic factor have been shown. This ultimately leads to increases in brain derived neurotrophic factor (BDNF) (Walsh, Smith, Northey, Rattray, & Cherbuin, 2020). BDNF has been shown to increase synaptic plasticity, enhance information processing and increase the rate of learning. Changes in neurotransmitter levels have also been shown. Increases in serotonin, noradrenaline and dopamine have been documented after chronic bouts of physical activity. These changes are associated with improvements in mood and arousal and have been shown to be instrumental in executive function of the prefrontal cortex (Zhou et al., 2022). Bradley et al. conducted a randomized controlled trial with 202 children to determine the effect of physical activity on academic achievement in school. Analysis of data found a significant relationship between math scores and the amount of vigorous physical activity the children were involved in. On the contrary, reading scores were not associated with physical activity (Sember, Jurak, Kovač, Morrison, & Starc, 2020). A proposed reason for this is that cardiovascular exercise, which has a positive effect on cognitive function, is more integral in the learning and application of math skills. This may be due to the reinforcing nature of math with constant revision and practice accelerating the rate of learning. Other possible reasons for the positive association between physical activity and math scores are the problem-solving nature of mathematics and the fact that cardiovascular exercise increases the production of neurotrophic proteins in the brain which improve synaptic connections. Bradley et al. found this to be true in the case of older children, yet for younger children there remained a significant relationship between physical activity and reading scores (Cichy et al., 2020).

The result of the present paper has also shown that engaging in physical activity can enhance cognitive abilities such as logical thinking, and numerical processing, all of which are essential components of arithmetic reasoning. Regular physical activity promotes brain plasticity, which allows the brain to adapt and reorganize, leading to improvements in cognitive function over time. Additionally, exercise has been shown to reduce stress and anxiety, which can positively impact performance in tasks requiring arithmetic reasoning.

Although the current study offers support for the positive correlation between physical activity and mathematical performance, some limitations of this study deserve consideration. Initially, it is important to note that the study is constrained by its focus on students from a single educational institution. Consequently, generalizing the results to students from different schools or diverse backgrounds may not be appropriate. Additionally, the study's small sample size (N=104) led to challenges in participant recruitment, posing another limitation. Another constraint was the absence of an assessment of the lasting impacts of physical activity on cognitive functions. Furthermore, the study's narrow age range and data collection from a single time point limit its scope. Therefore, future research should aim to investigate similar variables on a more diverse sample encompassing students from elementary, middle, and high schools. Nonetheless, the findings obtained can offer valuable insights for future investigations. The strength of this research lies in its effective approach to enhancing physical fitness, academic achievement, and psychosocial aspects.

Conclusions

In today's knowledge-based economy, mathematical skills are highly valued in the workforce. Individuals with poorly developed mathematical competencies may face challenges in accessing employment opportunities and advancing in their careers. Moreover, mathematical competencies are essential for navigating various aspects of daily life, including managing finances, interpreting data, and making informed decisions. Children with mathematical disabilities may experience difficulties in these areas, affecting their independence and quality of life. By addressing mathematical difficulties early and implementing evidence-based interventions, we can help children develop the mathematical competencies they need to succeed academically, professionally, and personally in the modern world. Overall, classroom-based physical activity is a valuable strategy for promoting physical health, cognitive function, and academic achievement among students. By integrating movement into the school day, educators create a holistic learning environment that supports the overall development and well-being of students.

This current study takes the further step in showing that a physical activity program in the classroom is a feasible method for improving mathematics performance in youth. By doing this, it is our hope that sufficient evidence can be provided to inform education policy and practices concerning the allocation of time for physical education and the role of physical activity in the academic curriculum. Teachers, parents, and policy makers need to understand that physical activity and academic achievement are not antagonistic to one another, but instead they can be worked in tandem to improve both health and learning.

Authors’ Contribution: Author 1 wrote designed the study, conducted the research, collected data, carried out the statistical analysis, was involved in the interpretation of data, wrote and revised the manuscript. Author 2 collected data, was involved in the interpretation of data and revised the manuscript. This article is the result of a study designed and shared between the authors. The Authors intellectually contributed to the manuscript, read the manuscript, and approved the presentation in the same way.

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Authors’ contribution
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