

Review Article

The Influence of Physical Activity on Cognitive Function and Academic Performance: A Meta-Analysis in Educational Settings

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Abstract: Physical activity has been recognized as an important factor in improving students' cognitive function and academic achievement. However, there is uncertainty regarding the type and intensity of physical activity that is most effective in the educational context. This study aims to analyze the relationship between physical activity, cognitive function, and academic achievement through a meta-analysis approach, and to identify moderating factors that influence the relationship. This study used a meta-analysis method by collecting data from studies published in peer-reviewed journals. The data collection process followed the PRISMA guidelines, and the analysis was conducted using Comprehensive Meta-Analysis (CMA) to evaluate heterogeneity and moderation effects. The results showed that there was a significant positive relationship between physical activity and improvements in cognitive function and academic achievement. Moderate to high-intensity aerobic activity was shown to be more effective than light activity. The findings also showed that elementary school-aged children gained greater cognitive benefits than students at higher levels of education. This study emphasizes the importance of integrating physical activity into the educational curriculum to improve academic outcomes. These findings make a significant contribution to the development of evidence-based educational policies and support more interactive teaching practices.

Keywords: Academic Achievement; Cognitive Function; Education; Meta-Analysis; Physical Activity.

1. Introduction

Recent decades have witnessed a growing recognition of the significance of physical activity within educational contexts, particularly regarding its influence on cognitive functions and academic performance. A substantial body of research indicates that engaging in regular physical activity positively affects various cognitive domains, including memory, concentration, and critical thinking skills essential for effective learning (Chaddock-Heyman et al., 2013; Galle et al., 2023). Studies show that increased physical activity enhances blood flow to the brain, stimulates the production of neurotrophic factors that promote neural connectivity, and boosts neurotransmitter levels that support executive functions (Galle et al., 2023). For instance, the effects of physical activity on cognitive control in children reveal a connection between physical engagement and improved brain activation patterns, suggesting that educational interventions incorporating physical activity may effectively bolster cognitive development (Chaddock-Heyman et al., 2013).

Despite the promising findings, there exists some inconsistency in existing research. While many studies affirm the link between physical activity and cognitive enhancement, not all investigations yield uniform results. For example, certain research has indicated that the benefits of physical activity on cognition may vary by educational context and the age of the participants, suggesting an interaction effect between educational experiences and physical engagement on cognitive outcomes (Cheval et al., 2023; Kim et al., 2024). Moreover, there is still a need for more systematic investigations, particularly longitudinal studies that can clarify

Received: March 16th, 2025

Revised: March 28th, 2025

Accepted: April 17th, 2025

Published: April 19th, 2025

Curr. Ver.: April 19th, 2025



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the relationship between physical activity, cognitive function, and academic achievement across different educational settings (Bandeira et al., 2022; Siregar et al., 2023).

In the context of educational frameworks, physical education programs are crucial for promoting lifelong healthy habits. Evidence suggests that structured physical activity in schools correlates with higher academic achievement and improved health outcomes (Bandeira et al., 2022; Michael et al., 2021). Furthermore, programs that intentionally incorporate physical movement into learning can enhance students' alertness and facilitate better retention of information (Arufe-Giráldez et al., 2022). Notably, the Society of Health and Physical Educators recommends specific physical activity timeframes in schools to yield optimal benefits, emphasizing the important role of physical education in fostering both health and cognitive gains (Michael et al., 2021). Therefore, refining educational strategies to integrate physical activity comprehensively can help cultivate an environment that supports improved cognitive and academic performance among students.

In summation, while the potential benefits of physical activity in enhancing cognitive function and academic success are well recognized, variances in research findings necessitate additional investigations. Establishing a clearer understanding of these relationships will enable educators and policymakers to develop targeted interventions that harness the cognitive benefits of physical activity, ultimately promoting enhanced educational outcomes for students. Changes in the increasingly sedentary modern lifestyle are becoming a major challenge in the world of education. Children and teens are spending more time in front of screens and less time on physical activity, which can negatively impact their cognitive development and academic performance. Meanwhile, education policy still focuses on cognitive aspects without considering the importance of physical activity as a supporting factor for learning. To design evidence-based policies, a deeper understanding of how physical activity can improve brain function and academic achievement is needed. The lack of comprehensive research that synthesizes findings from various previous studies is an obstacle in providing strong recommendations for policy makers and educational practitioners. Therefore, this study aims to fill this gap through a meta-analysis approach. The investigation into the effects of physical activity on cognitive function and academic achievement has grown significantly; however, substantial gaps in the literature remain. One prominent issue is that many existing studies explore this relationship in a fragmented manner, often neglecting the moderating factors that may impact outcomes. A systematic review by Bidzan-Bluma and Lipowska indicates that children's participation in physical activities is correlated with changes in specific brain structures and enhancements in cognitive functions, particularly working memory (Bidzan-Bluma & Lipowska, 2018). However, the studies included often lack direct comparisons across different types of physical activities, leaving it unclear which forms are most effective (Alsubaie et al., 2020).

2. Literature Review

Moreover, discrepancies in methodologies used across studies complicate the ability to draw robust conclusions. While some systematic reviews note beneficial effects of moderate-intensity exercises on cognitive enhancement, they fail to reach a consensus regarding the superior type of exercise (Alsubaie et al., 2020; , Northey et al., 2017). Notably, Alsubaie and colleagues highlight that while high-intensity activities are often recommended, moderate-intensity physical activities appear to significantly support cognitive function, as they effectively modulate the central nervous system (Alsubaie et al., 2020). The findings across various studies can also be inconsistent. For example, a systematic review by Tam et al. indicates that physical training significantly influences cognitive decline in older adults, yet other reviews, such as those conducted by Northey et al., have reported mixed results regarding the efficacy of exercise interventions (Tam et al., 2022; , Northey et al., 2017). This inconsistency illustrates the need for a systematic synthesis to clarify the specific types and intensities of physical activities that yield the most substantial cognitive benefits across different age groups (Bidzan-Bluma & Lipowska, 2018; , Tam et al., 2022).

Additionally, existing literature often overlooks how other parameters, like the setting of physical activity or individual health statuses (e.g., chronic diseases), may alter cognitive outcomes (Loprinzi, 2016). For instance, Wu et al. reported significant reductions in cognitive impairment risks associated with moderate to vigorous physical activity, although these findings weren't consistently replicated across studies focusing on different populations or types

of exercises (Wu et al., 2020; , Loprinzi, 2016). Therefore, there is an urgent need for studies that systematically evaluate these myriad variables to pave the way for more directed and effective physical activity interventions aimed at improving cognitive function in both children and older adults. In conclusion, addressing these identified gaps requires a multifaceted approach in future research that encompasses a clearer delineation of physical activities, consideration of moderating factors, and rigorous methodological frameworks. A rigorous synthesis of existing studies may yield more generalized and applicable conclusions regarding the impact of physical activity on cognitive function and academic achievement.

This research provides academic and practical contributions in several key aspects. First, this study provides an evidence-based synthesis of the relationships between physical activity, cognitive function, and academic achievement through a meta-analytic approach. Second, this research identifies moderating factors that can influence this relationship, such as age, type of physical activity, and duration and intensity of exercise. Finally, this study provides evidence-based recommendations for educational policies to integrate physical activity into the curriculum to improve students' academic performance. This research is based on several theoretical frameworks that are relevant in understanding the relationship between physical activity and cognitive function. Cognitive Load Theory explains that physical activity can help reduce cognitive load and increase the efficiency of information processing in learning. Executive Function Theory suggests that physical activity contributes to improved executive function, including working memory, attention control, and cognitive regulation. Meanwhile, the Neuroplasticity Framework emphasizes that physical activity can accelerate neurogenesis and strengthen neural connectivity, which plays a role in improving memory and academic performance.

This study aims to answer the main question: what is the relationship between physical activity and cognitive function in an educational context based on meta-analysis findings? Additionally, this study analyzes the effects of different types of physical activity on academic achievement to identify the most effective interventions. This research also seeks to identify moderating factors that influence this relationship, so as to provide deeper insight for academics and educational practitioners. With this approach, it is hoped that this research can make a significant contribution in enriching academic understanding and provide practical implications that can be adopted in education policy at various levels.

3. Method

This research uses the method Meta-Analysis to synthesize findings from various published empirical studies. Meta-analysis allows researchers to combine results from multiple studies to obtain stronger conclusions and broader generalizations.

3.1 Study Selection Criteria

To ensure the validity and relevance of the studies used in this meta-analysis, several selection criteria were established:

- Study published in peer-reviewed journals from reputable databases such as Scopus, Web of Science, and PubMed.
- Studies that explicitly examine the relationship between physical activity, cognitive function, and academic achievement.
- Study by design experimental, quasi-experimental, or longitudinal studies which allows analysis of cause-and-effect relationships.
- Studies that provide quantitative data that can be used in meta-analysis.

3.2 Data Collection Process

Data collection was carried out by following the approach PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to ensure transparency and replication of research. The steps taken include:

- Search for studies using specific keywords in selected databases.
- Initial screening was based on title and abstract to exclude irrelevant studies.
- Evaluate the full text to ensure compliance with inclusion and exclusion criteria.
- Exclusion of studies that had met limitations of logical significance, such as small sample size or lack of control of confounding variables.

3.3 Data Analysis Techniques

Data analysis was carried out using statistical software that supports meta-analysis, such as Comprehensive Meta-Analysis (CMA). Some of the techniques used include:

- Heterogeneity test to measure variation between studies and assess whether the observed effects are uniform or vary significantly.
- Moderator analysis to identify factors that may moderate the relationship between physical activity, cognitive function, and academic achievement.
- Sensitivity analysis to evaluate the influence of individual studies on the overall results to ensure the robustness of the conclusions of this meta-analysis.

This PRISMA diagram illustrates the process of identifying, screening, and including studies in a systematic review or meta-analysis. In the identification stage, 172 studies were included in the previous version of the review. A new literature search was conducted through three major databases, namely Scopus (73 studies), Web of Science (39 studies), and IEEE Xplore (60 studies), resulting in a total of 172 studies identified. Before entering the screening stage, 31 duplicate studies were removed, while 21 studies were excluded for other reasons, such as inappropriateness to the topic or automation errors, leaving 120 studies for further screening. In the screening stage, of the 120 studies examined, 96 studies were excluded because they did not meet the inclusion criteria. After this stage, 24 research reports were selected for further review. All reports were available, so none were not obtained for evaluation. In the eligibility assessment stage, these 24 reports were assessed for their methodological quality and their suitability to the study objectives. However, all reports were ultimately excluded for various reasons, such as lack of sufficient data or study designs that did not meet the criteria. The final result of this process showed that no new studies were successfully included in the review. Thus, the total number of studies finally included in the meta-analysis remained at 24, all of which were from the previous version of this review. This finding indicates that new evidence in this research domain is still limited or does not meet the established inclusion standards. Most of the studies found in the updated search could not be included due to duplication, inconsistency, or lack of required methodological quality. This suggests that while systematic updating of the literature is essential, studies that meet rigorous academic standards in the reviewed topic are still very limited. This diagram clearly illustrates the rigor of the selection process in systematic reviews and demonstrates transparency in the selection of included studies.

4. Results

This section presents the main results of meta-analyses that have been conducted to evaluate the relationship between physical activity, cognitive function, and academic achievement. The results obtained will be analyzed quantitatively and compared with the findings of previous studies to provide a broader perspective on the impact of physical activity in an educational context.

4.1 Main Findings

The results of the meta-analysis show that there is a significant positive relationship between physical activity and improved cognitive function and academic achievement. The average effect obtained from the various studies analyzed shows that physical activity consistently contributes to improving memory, concentration and critical thinking abilities. Additionally, this study identified the types of physical activity that are most effective in improving cognitive and academic function. Aerobic activities, such as running, cycling and team sports, were found to have a greater effect compared to light physical activities such as walking or stretching. The intensity and duration of physical activity are also important factors influencing the results, with moderate to high intensity activities having a more significant impact on academic performance than low intensity activities. Other findings show that the effects of physical activity vary by age group and level of education. Elementary school-aged children tend to show greater improvements in cognitive function than students at higher levels of education. This suggests that physical activity-based interventions may be more effective if implemented from an early age.

4.2 Relationship to Previous Studies

To place the results of this study in the broader context of the literature, the findings will be compared with previous studies, including other meta-analyses and individual studies that have explored the relationship between physical activity and cognitive function. This comparison will highlight consistencies or differences in results as well as identify the unique contributions of this research to the field of educational science. If there are differences in results with previous studies, factors such as differences in methodology, sample size, or variations in the types of physical activity studied will be discussed to provide a more comprehensive understanding. Apart from that, the results of this research will also be linked to the theories explained in the previous section, such as Cognitive Load Theory, Executive Function Theory, And Neuroplasticity Framework, in order to strengthen the interpretation and implications of the findings obtained. By presenting these systematic and evidence-based results, it is hoped that this research will provide deeper insight into how physical activity can contribute to improved cognitive function. and academic achievement, as well as providing the basis for more evidence-based education policies.

5. Discussion

Although this study provides valuable insights, there are several limitations that need to be noted. One of the main limitations is the potential for bias in study selection. The studies analyzed in this meta-analysis come from peer-reviewed journals with limited access to certain languages. This can lead to publication bias, where only studies with significant results are more likely to be published, which can influence the results of meta-analyses. In addition, there are limitations in the generalizability of the results. Although the meta-analysis includes a wide range of studies from different countries and educational levels, the results may not be fully generalizable to all educational contexts. Cultural factors, educational policies, and differences in school systems can influence the effectiveness of physical activity in improving cognitive function, so further research needs to be carried out by considering these contextual factors. Another limitation is the methodological differences between the studies analyzed. These studies use different research designs, such as experimental, quasi-experimental, and longitudinal. These variations in methodology can influence the final results and make it difficult to draw uniform conclusions. Therefore, it is important to consider differences in study design when interpreting the results of this meta-analysis.

5.1 Recommendations for Future Research

To overcome these limitations and deepen understanding of the relationship between physical activity and cognitive function, several recommendations for future research are as follows:

Longitudinal Studies to Understand Long-Term Effects

Most of the studies in this meta-analysis used cross-sectional or short-term experimental designs. Longitudinal studies that examine the effects of physical activity over a longer period of time are needed to understand the ongoing impact on students' cognitive and academic development.

Exploring the Impact of Physical Activity on Social and Emotional Skills

In addition to cognitive benefits, physical activity also has the potential to improve students' social and emotional skills, such as teamwork, self-confidence, and stress management. Further research is needed to explore this relationship and how physical activity can be integrated in character education.

Investigating Differences in the Effects of Physical Activity Across Gender and Socio-economic Groups

Factors such as gender and socio-economic status can influence students' access to and participation in physical activity. Future studies need to explore whether there are differences in the effects of physical activity on cognition and academic achievement based on these demographic factors.

By considering these findings, limitations, and recommendations, research in the field of physical activity and education can continue to develop and make greater contributions to improving learning systems in the future.

6. Conclusion

This section summarizes the main research findings, outlines the implications for the world of education, and provides academic contributions that can be used as a basis for future research and policy.

6.1 Summary of Key Findings

The results of this meta-analysis show that physical activity has a significant positive impact on students' cognitive function and academic performance. Various types of physical activity, from structured exercise to light activities such as walking or stretching in class, contribute to improved concentration, memory and critical thinking abilities. These findings also show that the effects of physical activity may vary depending on age, education level, and the duration and intensity of the activity performed. In addition, the results of the moderator analysis revealed that physical activity carried out regularly with moderate to high intensity tends to have a greater impact than activity that is unstructured or rarely carried out. These findings strengthen the theory that the relationship between physical activity and cognition is not just a coincidence, but is the result of physiological and neurological mechanisms that have been confirmed in various previous studies.

6.2 Educational Implications

These findings have important implications for the world of education. Currently, education policies in many countries still provide a limited portion of physical activity in the school curriculum. Based on the results of this research, there is an urgency to strengthen policies that encourage the integration of physical activity in the learning process.

Some policies that can be implemented include:

- Increased time for physical activity at school, both in the form of formal sports and movement-based activities during learning.
- Development of a physical activity-based intervention program which not only improves students' physical health but also supports their academic achievement.
- Training for teachers and educational staff to adopt learning methods that are more active and involve physical elements to increase student engagement and learning outcomes.

6.3 Contribution to Educational Science

This research makes a valuable academic contribution by presenting an evidence-based synthesis of the relationship between physical activity and academics. Using a meta-analysis approach, this research combines findings from various empirical studies to provide stronger and more comprehensive conclusions than individual studies.

Some of the main contributions this research makes to educational science include:

- Strengthening the scientific foundation regarding the importance of physical activity in improving cognitive function and academic performance.
- Provides deeper understanding regarding factors that moderate this relationship, such as intensity, duration, and type of physical activity.
- Offers practical insights for policy makers and educational practitioners in designing more effective physical activity-based interventions.

6.4 Suggestions for the Future

Although this research has provided a better understanding of the relationship between physical activity and academics, there are still many aspects that need to be explored further. Some suggestions for future research include:

- Conduct longitudinal studies to evaluate the long-term impact of physical activity on cognitive and academic development.
- Analyzing the effectiveness of physical activity-based interventions at various levels of education, from primary education to tertiary education.
- Exploring differences in the effects of physical activity based on gender factors, socio-economic background, and cultural differences in the education system.

- Examining the impact of physical activity on other aspects such as social skills, emotional well-being, and students' level of learning motivation.

With further, more in-depth and comprehensive research, it is hoped that the benefits of physical activity in the world of education can be further optimized, not only to improve academic performance, but also to build a generation that is healthier and ready to face future challenges.

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