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Review

Physical activity and cognition in adolescents: A systematic review

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ABSTRACT

Objectives: The purpose of this report is to perform a systematic review of the evidence on the associations between physical activity and cognition by differentiating between academic and cognitive performance measures. Second-generation questions regarding potential mediators or moderators (i.e., sex, age and psychological variables) of this relationship were also examined.
Design: Systematic review.
Methods: Studies were identified from searches in PubMed, Sportdiscus and ERIC databases from 2000 through 2013. The search process was carried out by two independent researchers.
Results: A total of 20 articles met the inclusion criteria, 2 of them analyzed both cognitive and academic performance in relation to physical activity. Four articles (18%) found no association between physical activity and academic performance, 11 (50%) found positive association and one showed negative association (5%). Five articles (23%) found positive association between physical activity and cognitive performance and one showed negative association (5%). The findings of these studies show that cognitive performance is associated with vigorous physical activity and that academic performance is related to general physical activity, but mainly in girls. Results of the review also indicate that type of activity and some psychological factors (i.e., self-esteem, depression) could mediate the association between physical activity and academic performance.
Conclusions: Results of the review support that physical activity is associated with cognition, but more research is needed to clarify the role of sex, intensity and type of physical activity and some psychological variables of this association.

1. Introduction

Cognition, a wide term to refer to cognitive and academic performance, is a mental function involved in gaining knowledge and comprehension. A high cognition has been identified as a positive marker of health.[1] Likewise variables associated with cognition have been used to assess psychological health of school aged individuals.[2] Specifically, adolescence is a critical stage for cognition,[3] and cognition in adolescents may be an important predictor of adult health.[4,5] For example, poor cognition during adolescence has been associated with higher morbidity and mortality,[6,7] anxiety disorders,[8] depression,[9] psychological distress,[10,11] coronary heart disease[12] and some cancers later in life.[13] High cognition is linked to positive psychological-related variables such as self-esteem and self-concept.[14] A healthy lifestyle during adolescence may be crucial for better cognition.[15]

Habitual physical activity may be a key determinant of cognition during adolescence,[2,16–19] which is the period of life with the greatest decline in physical activity levels across the lifetime.[20–22] A growing body of literature suggests that physical activity has a clear influence on cognition measures such as concentration, working memory, inhibition and classroom behavior during these ages, aspects that are the foundation for academic abilities.[23–25] By contrast, some studies have also shown contradictory evidence regarding the link between physical activity and cognition.[26,27] This contradictory evidence might be due to the fact that academic performance is arbitrarily assessed by academic and cognitive measures. According to conceptualization proposed by Keeley,[26] cognitive performance is mainly related to psycho-physiological shifts in cerebral function, whereas academic performance is associated not only with cognitive performance, but also with family background and environment, teacher perception, and the quality and quantity of academic teaching.[28] Thus, some studies showed that academic and cognitive measures were moderately correlated with each other in adolescents.[29] Therefore, it is possible that separately investigating academic and cognitive performance in

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adolescents would help to clarify their association with physical activity.

Two previous reviews in school-children aged 5–18 years collectively reported the positive effect of physical activity on cognition.[17,18] However, our revision is focused specifically on studies in adolescents. Brain plasticity changes with age[3] and there is some evidence that physical activity stimulates some factors involved in brain plasticity, such as brain-derived neurotrophic factor (BDNF).[30] Age could therefore be a critical factor in the relationship between physical activity and cognition.

This review also analyzes the selected studies aimed at identifying potential moderating (i.e., interaction variable that affects the direction and/or strength of the relationship between exposures and outcomes) or mediating (i.e., intervening variable that is on the causal pathway between exposures and outcomes) variables in the link between physical activity and cognition in this age group such as cognition assessment, sex, physical activity intensity level, and various psychological variables. To our knowledge, there is no review that takes these possible moderator or mediator interactions into account. Finally, our review also expands on the previous research by including studies up to 2013.

To conclude, the purpose of this report is to systematically review the evidence of association between physical activity and cognition by differentiating between academic and cognitive performance measures. In addition, this paper also reviews potential mediators and moderators (i.e., sex, age and psychological variables) that may modify the association between physical activity and cognition.

2. Methods

2.1. Selection of the literature

During March 2014, a comprehensive search of three databases of literature (PubMed, Sportdiscus and ERIC) from 2000 through 2013 was undertaken (Table 1). The principal search terms were as follows: (1) "academic performance" (cognitive performance, academic achievement, performance at school, and academic outcomes), (2) "physical activity" (physical education, sport, athletic participation and exercise behavior), and (3) "adolescent" (children, school-age youth, student, school and childhood).

2.2. Inclusion criteria

A predetermined set of inclusion criteria was used to select papers for this systematic review. Each study had to meet the following criteria:

(1) It included a population that has to overlap with high-school-aged adolescents between 13 and 18 years. This adolescent age range is based on the U.S. National Institutes of Health's National Library of Medicine (*age criterion*).
(2) It reported a cross-sectional, longitudinal or interventional study design (*study design criterion*).
(3) It aimed to determine the association of physical activity with academic or cognitive performance (*relationship criterion*).
(4) It described at least one academic or cognitive performance measurement (*measurement criterion*).
(5) It was an article published in English or Spanish (*language criterion*).

2.3. Data extraction and reliability

A standard data extraction template was developed to extract the main details for every eligible study in terms of author, title, objective, sample size, country, design, physical activity measurement, cognition measurement and results about the relationship between physical activity and cognition. These first details were used as a basis of the evidence tables. Finally, the search process was carried out by both researchers (I.E. and CM.T.). A single researcher (I.E.) examined every title and abstract to identify a potentially relevant paper for review. In case of uncertainty, a second researcher (CM.T.) checked the selection process.

3. Results

3.1. Search results

The flow of citations through the systematic review process is shown in Fig. 1. A total of 608 results were returned. After removing 47 duplicates, this search retrieved 561 unique citations. A total of 436 articles were rejected at title and abstract level. Subsequently, full-text copies of 125 potentially relevant citations were obtained and reviewed. Of these 125 papers, a total of 106 articles were excluded. Therefore, 19 unique citations passed the eligibility criteria and were included in the systematic review. After review of their reference lists, one further paper that satisfied the inclusion criteria was added.

3.2. General

This review examines the findings of 20 studies[15,27,31–48] that explored the relationship between physical activity and cognition. Of these, 75% of studies[15,31–44] were of cross-sectional design, 15% were longitudinal studies[27,45,46] and 10% were interventional studies.[47,48] The sample size varied from 48 participants[41] to 75 066 participants.[43,44] Information about all the studies is chronologically presented in Table S1.

3.3. Physical activity measurement

Physical activity patterns were examined using self-report measures among 19 studies,[15,27,31–41,43–48] six of these studies showed the validity of the self-reported physical activity questionnaires,[34,38,40,41,45,47] and only one study used objective measure of physical activity.[42] Five studies assessed physical activity taking into account only athletic participation[15,27,36,46] (i.e., individual sport activities and team athletics) or physical education.[43] Seven studies[37–41,44,48] used questionnaires without recalling each day specifically, to estimate weekly physical activity. One of these studies[39] also examined self-reported active commuting to school. Seven studies[31–35,45,47] used physical activity recall questionnaires reporting in detail each day.

3.4. Cognition measurement

3.4.1. Cognitive performance measurements

Cognitive performance measurements took into account a large variety of skills, including reading, mathematics, reasoning, science and social studies. Two studies[15,39] used the SRA (Science research associates) Test of Educational Ability to assess verbal, numeric and reasoning abilities. Two studies[27,47] examined cognitive performance using a standardized test score. One of them[27] used composite tests in reading, math, science, and history and the other study[47] used the Terra Nova test, which consisted of multiple assessments of reading or language arts, mathematics, science, and social studies. Two studies[40,48] used a narrow variety of skills. One of them[40] selected two subtests from the BADYG (battery of differential and general aptitude) to assess oral and math skills, and

Table 1
Search strategy in databases.

Database	Search Strategy	Limits
PubMed	("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior) AND ("academic performance" OR academic achievement OR performance "at" school OR academic outcomes OR cognitive performance) AND (adolescent OR children OR student OR childhood OR school-age youth OR school) NOT 2014[dp]	Publication date from 2000/01/01 to 2013/12/31 Species: Humans Ages: Adolescent: 13–18 years
SportDiscus (EBSCO)	(TI ("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior)) AND (AB (academic performance OR academic achievement OR performance at school OR academic outcomes OR cognitive performance)) AND (AB (adolescent OR children OR student OR childhood OR school-age youth OR school))	Publication date from 2000/01/01 to 2013/12/31. Document type: Journal article
ERIC (EBSCO)	(TI ("physical activity" OR "physical education" OR sport OR athletic participation OR exercise behavior)) AND (AB (academic performance OR academic achievement OR performance at school OR academic outcomes OR cognitive performance)) AND (AB (adolescent OR children OR student OR childhood OR school-age youth OR school))	Publication date from 2000/01/01 to 2013/12/31, Document type: Journal article

the other one[48] used a 2-min mathematics task performing simple additions to evaluate numeric ability.

3.4.2. Academic performance measurements

Academic performance was assessed using self-reported grades or grades reported by schools. Nine studies[33,35–38,43–46] used self-reported grades, six[27,31,32,41,42,47] used grades reported by schools, and one study[34] used both kinds of reporting. Six studies[27,32–34,41,42] used all subjects (including Physical Education), two studies[31,45] used English, Math and Science. History was added to these subjects in one study[46] and World Studies in another.[47] English, Math and Danish (or Swedish or Norwegian), were used in one study,[38] and these together with Icelandic in another.[35] One study[37] used Math and Natural Sciences (such as biology, chemistry and physics), and included Finnish and general subjects (such as History and Religion). However, three studies[36,43,44] did not specify any subjects. Math was the unique common subject included in all studies.

3.5. Relationship between physical activity and cognition

Collectively, 70% of studies examined the relationship of physical activity with academic performance,[27,31–38,41–47] whereas 30% of studies examined the relationship between physical activity and cognitive performance.[15,27,39,40,47,48] From all studies, 20% found no associations,[31,33,37,45] while 80% found association, 70% of associations positive[15,27,32,36,38–44,46–49] and 10% negative.[27,34]

3.5.1. Physical activity and cognitive performance

Results across six studies showed significant associations. Five studies[15,39,40,47,48] determined positive associations and one longitudinal study[27] reported negative associations. This longitudinal study[27] reported sport participation among twelfth-grade students remained negative for cognitive performance after controlling for potential confounders including academic performance in previous grades. Moreover, when the type of sport participation is defined (i.e., individual vs. team sport), team sport participation remained negative for cognitive performance, whereas there was no association with participation in individual sports.

The two intervention studies[47,48] specifically analyzed the association between timing of physical education classes and cognitive performance. One of them[48] noted that the timing of physical education classes during the school day (i.e., morning vs. afternoon) may influence the results. Attending the 1st, 3rd, and 5th hour of the daily physical education classes was related to a significantly higher cognitive performance, while attending the 6th-hour class was associated with a decrease of cognitive performance. However, the other study[47] found that cognitive performance was not influenced by the timing across the year of physical education class enrollment (i.e., first or second semester). The same study showed[47] that increases in cognitive performance were associated

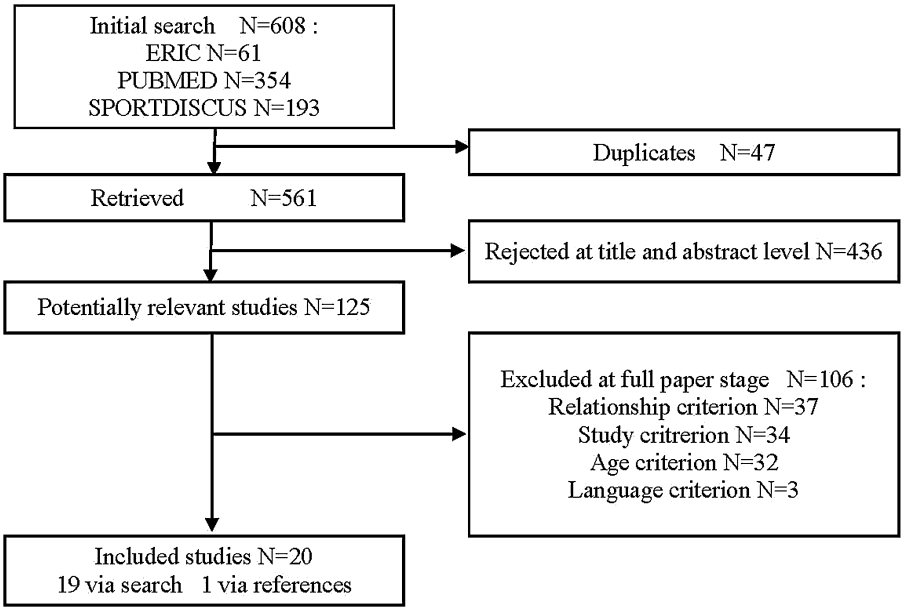

Fig. 1. Papers selection process.

with vigorous activity, but not with moderate physical activity. Likewise, Travlos[48] demonstrated that intense physical education classes had beneficial effects on youth cognitive performance. Nevertheless, these studies[47,48] conducted no analysis by sex.

By contrast, three studies[15,39,40] examined the moderating effect of sex. One study[39] found that active commuting to school was associated with better cognitive performance in girls but not in boys. However, the other two studies[15,40] found no differences by sex in results regarding participation in extracurricular physical activities. One of them[40] also examined the moderating effect of age and demonstrated that participation in extracurricular physical activity was related to better cognitive performance at younger ages.

3.5.2. Physical activity and academic performance

The relationship of physical activity and academic performance showed effects of different magnitudes. Four studies[31,33,37,45] found no association. One study[34] showed a negative association between moderate to vigorous physical activity (MVPA) and academic performance, independent of adiposity, and eleven studies[27,32,35,36,38,41–44,46,47] showed positive associations.

Four studies[36,42,44,47] found different associations of physical activity intensity levels with academic performance, most of them identifying differences by sex. One study[36] found that after adjusting for sociodemographic variables, there was an association between performing more hours of MVPA and a higher grade point average (GPA) for both genders, but after adjusting for sports team participation, this association was significant only for high school girls. Another study[44] found that there was a relationship of academic performance with vigorous physical activity only in boys and with moderate physical activity in both boys and girls. Likewise, other study[42] showed that vigorous physical activity was the only intensity level correlated with academic achievement, but solely in girls. This study also showed no mediating effect between physical activity and academic performance through fitness.[42] However, Coe et al.[47] noted that increases in academic performance were associated with vigorous activity and not with moderate physical activity, however, analysis by sex was not performed in this study.

Three studies[27,32,43] reported different associations between mode of physical activity and academic performance. One of them[27] determined that sport participation in twelfth-grade students was positively associated with academic performance after controlling for potential confounders including ratings at 8th and 10th grades. Moreover, team and extramural sport participation was greater associated with academic performance than individual and intramural sport participation. Another study[32] showed that the relationship between academic performance and minutes of weekly activity was weaker when time spent traveling to school was added to the total minutes of physical activity (i.e., physical education, school sport, and other activities). The other one[43] identified that attending three or more physical education classes per week was positively correlated with improved school performance. Moreover, Morales et al.[41] examined energy expenditure and showed greater academic performance for the "high" and "moderate" active groups than the "low" active group.

The moderating effect of sex on the association between physical activity and academic performance was specifically reported in four studies.[27,32,43,46] One study[46] showed that sports participation was associated with increases in GPA for girls, but not for boys. On the other hand, three studies[27,32,43] found no differences in their results by sex. Two studies[35,38] showed that some psychological factors (self-esteem, depression) seemed to mediate the association between physical activity and academic achievement. One of them[38] found physical activity was directly and positively related to academic achievement, but to a lesser extent when self-esteem was included. In addition, the other study[35] reported that the association between physical activity and academic performance become non-significant when depressed mood and self-esteem were included in the model.

4. Discussion

The current review summarizes all studies from 2000 to 2013 that met the defined inclusion criteria, regardless of study characteristics. Results from the studies included in the present systematic review suggested that physical activity is positively related to academic and cognitive performance in high school students. Nevertheless, only two are intervention studies[47,48] and three are longitudinal studies.[27,45,46]

Regarding to measurements, physical activity was assessed through self-reported questionnaires in the most of studies, few studies showed the validity of these questionnaires[34,38,40,41,45,47] and only one used objective measures of physical activity.[42] This fact indicated, and as previous reviews[17,18] pointed out, the necessity for future studies to assess physical activity objectively by using accelerometers. On the other hand, reviewed studies used either cognitive tests or grades to assess cognitive or academic performance, respectively, and only two studies[27,47] used both measures. A study in a large sample of adolescents showed that academic and cognitive measures were moderately correlated with each other (*r*s ranged from.27 to.57, $p < .001$).[29] Nevertheless, there was no agreement on an adequate method to assess cognition in the school context, nor regarding the use of school subjects to assess academic performance. Math was seen as the only included subject common to all studies. It is necessary, therefore, to further explore the association between physical activity and different types of cognition measures in future studies.

Most of the studies (approximately the 75%)[15,27,32,35,36,38–44,46–48] in the present review showed significant positive associations between physical activity and cognition, which allows drawing consistent conclusion in the association. According to Sallis et al. strong evidence of an association exists when 60% of studies find significant associations in the same direction.[50] Five studies reported this association with cognitive performance and eleven studies with academic performance and only two studies found a significant negative association of physical activity with cognitive[27] or academic performance.[34] Four studies found no association.[31,33,37,45] Several mechanisms have been suggested to explain a beneficial effect of physical activity on cognition.[51] The effect of exercise on the brain could be the result of several factors including increased flow of blood[52,53] and oxygen to the brain,[53] or higher levels of chemicals and increased activity-dependent synaptic plasticity.[54]

One study conducted with young male adults as subjects[55] reported that vigorous activity can increase brain-derived neurotrophic factor (BDNF) and catecholamines (dopamine and epinephrine). Findings from intervention studies in adolescents reported that vigorous physical activity was the only intensity level that significantly correlated with cognitive performance.[47,48] By contrast, academic performance was associated not only with vigorous physical activity,[42,44,47] but also with MVPA,[36,41] moderate-intensity[44] and light-intensity activity.[41] In this sense, different intensity levels of physical activity apparently have distinctive effects on cognitive and academic performance. It is possible to speculate that this could be due to a different "threshold" level of physical activity intensity being necessary to produce beneficial effects on cognitive and academic performance. Vigorous physical activity intensity levels seem to produce this beneficial effect on cognitive performance, but whether this intensity threshold is necessary for detectable effects on academic performance is not clear. Therefore, further prospective and experimental studies in adolescents are required to examine the optimal level of

physical activity (intensity and quantity), assessing sedentary-, light-, moderate-, and vigorous-intensity levels of physical activity, which may confer improved academic performance.

Moreover, physical education or sport participation provided a portion of students' daily physical activity, and these were positively related to cognitive[15,39] and academic performance.[27,43,46] However, these physical activities do not cover the complete range of physical activity in which youth are involved[49] (e.g., recess, lunch time or active commuting to school), and may confound the link of physical activity with cognitive and academic performance. For example, active commuting to school was associated with a better cognitive performance independent of extracurricular physical activity in girls.[39] By contrast, academic performance was more weakly related to physical activity when time actively commuting to school was added to the total minutes of physical activity.[32]

Overall, the 50% of reviewed studies that observed associations between physical activity and cognition in adolescents showed no analysis by sex,[35,38,41,47,48] or found no differences in outcomes by sex.[15,27,32,40,43] These findings were in line with a previous review from the US Department of Health and Human Services,[17] which focused on the association between school-based physical activity and academic performance. Our review expands the previous review by taking into account the moderating effect of several factors (e.g., sex and age) on the association of physical activity, with both academic and cognitive performance. Specifically, the sex-effect suggested that there was an association between more time spent in physical activity and higher cognitive[39] or academic[36,42,46] performance more frequently in adolescent girls than in adolescent boys. There was just one study which found effects favoring boys over girls, and solely in vigorous physical activity.[44] This tendency could be explained by the dose–response effect;[39] adolescent boys are more active than girls,[56] therefore, the stimulus achieved from lower levels of measured physical activity may not be sufficient in boys to produce the same physiological effect that was seen in girls, who were generally less active.[57] Based on the results drawn in our review, future studies should routinely analyze the moderating effect of sex on the association between physical activity and cognition.

Additionally, our review identified two other potential factors that may mediate the association between physical activity and cognition: self-esteem[35,38] and depression.[35] Specifically, the mediating effect of self-esteem seemed to play a key role in the relationship between physical activity and academic performance. Other sets of factors proposed in previous research that might mediate the association of physical activity with cognitive and academic performance were socioeconomic status (i.e., parental education and family structure),[35,42] absenteeism,[35] cardiorespiratory fitness and body mass index.[15] Consequently, these and other potential confounders such as genetic factors, fetal nutrition, cultural factors and physical activity in the school setting (recess activity, lunchtime activity or physical education) should be taken into account in future studies.

The strength of this review came from the extensive literature search using well-defined inclusion criteria to make advanced comparisons of the findings of full-text articles which passed the eligibility criteria. The examination of findings by academic and cognitive performance separately, the exploring of results by sex and the inclusion of studies conducted in different parts of the world, served to broaden the generalizability of our findings. Our study, however, has some limitations. Studies were not ranked or weighted, and as a result, findings from studies with weaker designs and smaller sample sizes were given no less importance than findings from studies with more rigorous research designs and larger sample sizes. The lack of assessment of bias, within and across studies. In this sense, findings must be interpreted with caution because we did not use a systematic strategy to reduce bias. Although, we tried to minimize selection bias by checking reference lists of previously published reviews, this in turn, may have resulted in an overrepresentation of studies with positive results. The fact that it was identified only two studies that included self-esteem and depression, which limits the possibility to draw conclusion regarding their mediating effect of the associations.

5. Conclusion

In conclusion, our findings support evidence of a positive relationship of physical activity with both cognitive and academic performance (approximately the 75% of studies supporting a positive association).[26,58] Cognitive performance seems to be associated with vigorous physical activity,[47,48] while academic performance seems to be related to general physical activity, mainly in adolescent girls.[36,42,46] In addition, some psychological factors, such as self-esteem and depression, could be involved in the association between physical activity and academic performance.[35,38] However, more intervention and prospective studies are warranted in order to clarify the mechanisms that affect this relationship in adolescents. Moreover, it would be of interest to investigate whether the optimal level of physical activity which may confer improved cognition in adolescents could be different for cognitive and academic performance.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.jsams.2014.07.007.

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