Mediators between physical activity and academic achievement: A systematic review

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Funding information
This study was funded by FEDER funds. The funder had no role in the design and conduct of the study

Background: Research has suggested the beneficial effects of physical activity (PA) on academic achievement (AA). However, the mechanisms underlying this influence remain unclear. Some proposed mechanisms include physiological, cognitive, psychological, and behavioral paths. This study aimed to analyze mediators between PA and AA in children and adolescents.

Methods: Systematic search in Medline, SPORTDiscuss, PsycInfo, Scopus, and Web of Science for observational and experimental studies, published up to March 2021.

Results: Twenty-eight studies (75237 participants, aged 4–16) were included. The designs of these studies were: 21 studies cross-sectional, 5 longitudinal, and 2 experimental. Eight out of nine studies analyzing fitness as a mediator reported positive results, and one reported null finding. Adiposity was a significant mediator in one study, in two only in girls, and two reported null results. Cognition as a mediator was supported by four studies, whereas two reported null results. Regarding mental well-being, 10 out of 14 studies reported positive effects, and one out of five behavioral studies found positive results. Although studies were too sparse to draw conclusions, overall, the results indicated that self-esteem, self-image, self-efficacy, stress, and health behaviors might be potential mediators in the relationship between PA and AA. All studies were rated as medium-high quality.

Conclusion: Overall, the available evidence seems to suggest that cardiorespiratory fitness, cognition, mental well-being, and exercise-related behaviors play some role as mediators of the relationship between PA and AA. However, the cross-sectional nature of most of the reviewed studies prevents us from making any statement in terms of causal paths. Thus, well-designed follow-up and randomized controlled studies aimed not only to test the effect of PA in AA, but also to examine the influence of mediators are required.

KEYWORDS
academic achievement, adolescents, children, mediator, physical activity, systematic review

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1 | INTRODUCTION

Recent research has suggested beneficial effects of physical activity (PA) on physical health, neurocognitive functioning, and academic achievement (AA). However, the mechanisms underlying this influence remain unclear. Thus, the association between PA and AA is complex and might be influenced by several mediators. Consequently, some lines of research have explored the intermediate variables underlying this association because this understanding could help to design effective physical exercise interventions to improve AA in children and adolescents.

Positive associations among PA, fitness, cognition, and AA have been reported, and PA may influence AA through changes in fitness, and cognition. Thus, a sequence of effects has been proposed. First, PA improves cognition (eg, attention, memory, inhibition, planning, or problem solving), and this, in turn, underlies improvements in AA. Others have suggested that the path between PA and AA is mediated through the positive influence of PA on cardiorespiratory fitness (CRF), which in turn improves cognition and, consequently, AA. Different neurobiological mechanisms have been proposed to explain these relationships; for example, an increase in CRF leads to greater cerebral blood flow, which promotes brain angiogenesis and neurogenesis and improves oxygen saturation. This then elicits an increased level of neurotransmitters and changes in the regulation of neurotrophins, especially in brain areas tied to executive function.

In addition, PA may be responsible for benefits in dimensions of mental well-being such as self-esteem, self-efficacy, social connectedness, or engagement, all of which result from PA and may also lead to improved AA. Moreover, participation in exercise activities may influence other healthy behaviors, such as sleep or diet, which are also associated with AA.

Most statistical models to explain these relationships use mediation analysis techniques. Mediation occurs when a third variable, the mediator, intervenes in the causal path between two variables. To quantify the magnitude and statistical significance of the mediation effect, researchers typically use statistical procedures based on multiple linear regression methods, usually following the causal steps proposed by Baron & Kenny, or structural equation modelling (SEM), a multivariate statistical technique that can be understood as an extension of regression models. To provide a graphical understanding of the mediation analysis, Figure 1 depicts a prototypical case of a single mediating variable.

A panel of experts on the relationship between PA and cognition and AA in children and adolescents highlighted that although research strongly supports the positive effects of PA on maths performance, high-quality research addressing the causal relationships between PA and cognitive performance, including the analysis of the main underlying mechanisms, is needed. A first step in this task could be to examine, through a comprehensive review, the mediation models that have been proposed to explain the mechanisms through which PA influences AA. Thus, the aim of this systematic review was to examine the available evidence about the mediating variables accounting for the relationship between PA and AA.

2 | MATERIALS AND METHODS

2.1 | Protocol and registration

This systematic review was reported according to the PRISMA 2020 statement and the MOOSE recommendations for observational studies. In addition, this review was registered in the PROSPERO International Prospective Register of Systematic Reviews (identifier CRD42020173284).

2.2 | Search strategy

Two authors (M.V.A. and A.R.H.) independently identified both observational and experimental studies published up to March 1, 2021, reporting mediation analysis that included PA as an independent variable and academic achievement-related variables as the outcome. The authors systematically searched Medline/PubMed, SPORTDiscus, Web of Science, Scopus, and PsycINFO using a search strategy that combined the following:

```
Physical Activity ----> Mediator e.g. executive functions
                           ^       ^
                          |       |
                        a-------b
Physical Activity ----> Academic achievement
Path c: Total effect of physical activity on academic achievement
Path c': Direct effect of physical activity on academic achievement
Path ab: Indirect (mediated) effect physical activity on academic achievement
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FIGURE 1 Prototypical example of a single mediating variable on the path from physical activity to academic achievement
terms: (1) “physical activity”, “exercise”, “physical education”, “sport”; (2) “academic”, “academic achievement”, “academic performance”, “academic grades”, “academic success”; (3) “children”, “childhood”, “pre-schooler”, “schoolchildren”, “kid”, “adolescent”, “preadolescent”; or (4) “mediators”, “mediate”, “mediation”, “mediation analysis”, “path analysis”, “structural equation model”, “structural equation modelling”, “regression models”, “multiple regression”, “indirect”, “indirect effect”, “SEM”, “causal pathway”. These criteria were restricted to title/abstract. In addition, the authors screened the reference lists of the articles included. The complete search strategy is presented in Table S1.

2.3 | Eligibility criteria

Primary source articles published in peer-reviewed journals were eligible for inclusion in this systematic review. Studies of the mediator variables of the relationship between PA and children’s and adolescents’ AA were eligible. Other inclusion criteria were as follows: (1) participants- healthy children and adolescents at developmental age, from 4 to 18; (2) exposure- studies including monitor-assessed or self-reported PA as an independent variable and studies considering PA participation, sports participation, exercise behaviors, and PA implementation across curricula; (3) outcome- AA assessed by curricular-based marks or a standardized test; and (4) study design- cross-sectional, longitudinal, and intervention studies that analyze mediator variables between PA and AA via regression-based models (mediation analyses, structural equation models, or multiple regression).

We excluded studies with any of the following characteristics: (1) included adult populations; (2) published in languages other than English or Spanish; (3) considered achievement only in the physical education domain; (4) review articles, meta-analysis, validation studies, conference abstracts, monographs, dissertations, theses, commentaries, or brief reports; and (5) populations with developmental disabilities, developmental delays, or cognitive impairment.

2.4 | Search and data extraction

Retrieved titles and abstracts were independently assessed for eligibility for inclusion in the review by two co-authors (M.V.A. and A.R.H.) and coded as “yes”, “no”, or “maybe”. The two co-authors were trained regarding study inclusion/exclusion criteria before completing the coding of abstracts. Eligibility assessments were reviewed by the first author, and any disagreements were discussed.

A Microsoft Excel spreadsheet was used to collect every step of the eligibility status of the reviewed studies.

The following data were extracted by the two co-authors from all eligible articles: (a) year of publication, (b) location, (c) study design, (d) sample size, (e) sample age, (f) PA measure, (g) main outcomes, (h) the main finding, (i) mediating variables proposed, (j) statistical method, and (k) control variables including socioeconomic status (SES), educational level of parents, PA level, health status, body mass index (BMI), and others. Disagreements were solved by discussion among the co-authors. Authors were contacted by email when missing data.

2.5 | Study quality and risk of bias

Two investigators independently assessed the methodological quality of the included studies using The Quality Assessment Tool for Observational Cohort and Cross-Sectional Studies and The Quality Assessment of Controlled Intervention Studies (National Heart, Lung and Blood Institute)22 to evaluate the risk of bias. This tool evaluates 14 items for longitudinal and intervention studies and 11 for cross-sectional studies. Each study was rated as follows: “good” when the study had the least risk of bias, and the results were valid; “fair” when the study was susceptible to some bias deemed not sufficient to invalidate its results; and “poor” when the study had a significant risk of bias. Studies rated poor were excluded from the body of evidence. Exceptions were allowed only if there was no other evidence available, in which case poor quality studies could be considered.23

3 | RESULTS

3.1 | Study selection

The electronic searches retrieved 1343 references. After the removal of duplicate studies, 1074 were reviewed based on title and abstract. Following this process, the full texts of 87 studies were reviewed. Two additional studies were identified after screening the reference lists of eligible articles. Finally, 28 eligible papers were included, and the selection process is shown in Figure 2.

3.2 | Study characteristics

The 28 selected studies published from 2000 to 2021 included 75237 children and adolescents aged 4–16 years, see Table 1. Twenty-one studies were cross-sectional,8,24–43 five were longitudinal44–48 (follow-up duration ranged from 7 months44...
to 3 years, and two were experimental. Sample sizes ranged from 51 to 22619 participants. Most of the studies were part of wider longitudinal and clinical trials.

### 3.3 Variable measures

#### 3.3.1 Exposure

PA was measured with monitor devices in 12 studies (11 with accelerometers and one with a pedometer) and self-reported with the following validated questionnaires in three studies: Physical Activity Questionnaire for Adolescents (PAQ-A) and the structured and unstructured PA Motorik Modul questionnaire (MoMo). Only one study measured PA both monitor-assessed and by self-report. Other studies did not report the amount of PA but reported sports participation, exercise behaviors, PA after school, school sports participation, sports participation after school hours, and self-reported moderate to vigorous physical activity (MVPA) with items on a Likert-type response scale. Finally, three studies assessed compliance with PA recommendations. The experimental studies consisted of two school-based physical activity interventions aimed at increasing PA activities as part of the mandatory school curriculum in comparison to regular activity, with a duration of 7 and 6 months, respectively.

#### 3.3.2 Outcome

AA was measured in the included studies as follows: 12 studies measured AA using the grade point average (GPA) in different subjects obtained from schools and one by separate domains, four studies provided a self-reported measure of AA by asking participants their grades in the core academic subjects, three studies used a GPA using standardized tests, which test children in different subjects and calculate a total score for the test and a final composite AA score, and eight studies analyzed the influence of variables in different domains of AA, such reading and maths, by using standardized tests of achievement.

#### 3.3.3 Mediators

Variables investigated as possible mediators on the path from PA to AA were grouped into four domains: fitness and adiposity, which included adiposity indicators (BMI and measures of body fat) and physical condition variables (CRF and other...
physical fitness components); cognition, which included several cognitive processes, such as attention, working memory, inhibition, cognitive flexibility, or cognitive self-regulation; mental well-being, which referred to variables such as stress, motivation, school well-being, self-concept and self-image, self-esteem, depression, and other clinical symptoms; and behavioral mechanisms, referred to daily health behaviors, such as bedtime, dietary patterns, or time spent in health activities. The results are summarized in Table S2.

### 3.4 Summary of evidence

Eighteen studies used SEM to test associations between variables and 10 used regression-based mediation analyses. In all studies, except for one, the analyses were controlled for covariates including SES and other familial characteristics. Body composition variables (BMI, body fat), puberty stage, age, race or ethnicity, mental health, time spent moving, learning and physical difficulties, achievement motivation, school absenteeism, screen time, after school behaviors, and seasonality (time of data collection) were also controlled in studies.

### 3.5 Cardiorespiratory fitness

Of the nine studies that analyzed the mediating role of fitness (eight evaluated CRF and one...
evaluated different physical fitness components), six of them reported an indirect effect of fitness on the relationship between PA (in its different forms) and AA (mostly the GPA between the different subjects). One study reported a null indirect effect, and another reported a mediating role of CRF between compliance with PA recommendations and AA in boys but not in girls. Finally, one study found that CRF was a mediator between total PA and maths but not between reading and writing.

3.6 Adiposity

Five studies analyzed the mediating role of adiposity variables, and one study found an indirect association between PA and AA via waist circumference; BMI mediated the association in girls but not in boys. However, three studies did not find a mediating role for BMI, body fat percentage, or waist circumference.

3.7 Cognition

Cognitive self-regulation was found to be a significant mediator between active play and maths and literacy in pre-schoolers. Another study found a partial mediation effect of cognition on the association between PA and reading and maths. Furthermore, inhibition/attention was a significant mediator between total PA and GPA and between total PA and maths achievement. Similarly, another study found a relationship between PA and AA via cognitive flexibility and a cascade relationship between PA and CRF, inhibition, and AA. However, in two studies (one longitudinal study and one experimental study), executive function did not mediate the relationship between PA and AA.

3.8 Mental well-being

Two studies explored the mediating role of depression in the relationship between PA and AA, reporting null results. Conduct problems, hyperactivity and inattention, and peer problems were found to be significant mediators in one study, whereas null findings were reported in another. Two studies showed that life stress and self-efficacy mediated the relationship between PA and AA. Three studies tested the mediating effect of self-esteem. One study found an inverse association between PA and AA, which was attenuated by improvements in self-esteem, and 2 studies found that self-esteem mediated the association between PA and AA. Similarly, one study reported a significant path via bodyweight image; however, another study found that physical self-concept did not mediate the association between PA and AA. The locus of control was reported as a significant mediator between sports participation and reading and maths, and two studies reported the mediation effect of maths self-concept in the relationship between PA and maths. In addition, two studies examined the mediating role of engagement during maths and well-being at school and reported null results. Nevertheless, school contentment and physical education interest, maths interest and maths self-confidence were found to be relevant mediators between physical education implementation and maths achievement.

3.9 Behavioral variables

Later bedtime mediated the association between self-reported MVPA and GPA only in girls in one study, and in another study sleep duration did not mediate the relationship between PA and AA. One study found a cascade association: physical education curriculum implementation was associated with healthy lifestyles, and healthy lifestyles were associated with maths interest and maths self-confidence, which in turn was associated with maths achievement. Moreover, a healthy lifestyle was indirectly associated with maths achievement via physical education interest and CRF. Conversely, MVPA in physical education and leisure time, engagement during maths, and the amount of MVPA in PE did not mediate the effect of a school-based physical education intervention on maths improvement or learning durations.

Finally, a summary of the mediators reviewed is displayed in Figure 3. The model is an adaptation of the model developed by Tomporowski et al.

3.10 Quality assessment

Twenty-three of the 28 studies were rated as good quality, and five studies were rated as fair. All studies situated their research question and analysis within the context of existing theoretical frameworks or provided a clear rationale for their mediation analyses, with previous evidence supporting cogent arguments for postulated relationships between exposure and outcome variables, exposure and mediator variables, and mediator and outcome variables. See Table 2.
4 | DISCUSSION

To our knowledge, this is the first systematic review in which the evidence regarding the potential mediators on the path between PA and AA in children and adolescents is summarized. CRF was the only variable to which the majority of studies attributed a statistically significant mediating role. Mixed results were reported for adiposity and cognition variables, and for mental well-being and behavioral mechanisms, the evidence was sparse. Several limitations are responsible for these inconsistencies, including the measurement instruments used, timing of data collection, and lack of adjustment for confounders. The cross-sectional nature of most studies precludes from drawing solid conclusions and temporal inferences.

4.1 | Fitness as a mediator

Eight out of the nine included studies reported a significant mediation effect of CRF in the relationship between PA and AA,\(^26,27,31,32,35,39,42,46\) in line with the results of a previous meta-analysis.\(^10\) Only in the study of Kwak et al.\(^30\) did the indirect effect not achieve statistical significance. Most likely, this difference may be attributable to a smaller sample size or PA measure, which may depend on PA intensity,\(^30\) or age sample, which has been reported to influence the associations between CRF and AA and to be stronger for children and preadolescents than among adolescents.\(^10\) Mostly, these results support the cardiovascular hypothesis that postulates that regular PA enhances CRF, which in turn enhances brain architecture by promoting structural changes in the cortex,\(^51\) basal ganglia,\(^52\) and hippocampus,\(^53\) and increases white matter integrity,\(^54\) and increase levels of neurotrophins.\(^13\) This promotes neurogenesis by increasing the levels of brain-derived neurotrophic factors, cerebral blood flow, synaptogenesis, and angiogenesis\(^55\) in specific brain areas, such that the prefrontal cortex is tied to learning and cognition.\(^14\) As a limitation, notice that most of studies were cross-sectional, except one,\(^46\) thus causal or direction inferences should be taken cautiously. Finally, for further studies, we recommend considering the effect age, sex, and different AA domains in these relationships.

4.2 | Adiposity as a mediator

Regarding adiposity, there were few studies, and their results and study designs are mixed. One longitudinal study reported a significant mediating effect in both sexes,\(^47\) and one cross-sectional only in girls.\(^26\) However, two cross-sectional\(^27,35\) and one longitudinal, did not,\(^48\) although their data point to the detrimental effect of adiposity on AA. Various reasons can be argued to justify the inconsistency of these results, including methodological differences among the studies, as well as the notion that PA and adiposity could be independent predictors of AA and that adiposity is not a mediator but a confounder. In addition, it has been speculated that obesity may affect girls’ self-esteem more strongly than boys’, explaining the stronger adverse association between body fat and AA in girls.\(^56\)
Thus, studies addressing in longitudinal and experimental designs the direct and indirect influence of adiposity on AA, as well as the potential moderating role of sex, are needed.

### 4.3 Cognition as a mediator

A growing body of evidence suggests that PA leads to cognitive benefits, which in turn improves AA.\(^9,12\) It has been hypothesized that the basis for the effect of PA on AA is that PA induces improvements in brain areas associated with cognition,\(^12\) especially the so-called executive function, by increasing the levels of neurotransmitters and changes in the regulation of neurotrophins.\(^13,14\) Moreover, neuroimaging studies have reported changes in the brain after single bouts of exercise or regular exercise.\(^57,58\) This hypothesis was supported by four of the cross-sectional analyzed studies.\(^33,38,42,43\) In contrast, longitudinal and experimental studies carried out by Aadland et al.\(^44,50\) did not find significant mediating effects of executive function. The included studies of cognitive mediators differed considerably in measures of PA, AA and test of cognition and, most importantly, in study design because the two studies reporting null findings were a longitudinal and an experimental study.\(^44,50\) On the other hand, some authors have suggested that the improvements from PA to AA mediated by cognition,

| Reference | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | Total |
|-----------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|------|
| Aadland et al.\(^44\) | Y | Y | Y | Y | NR | CD | NA | Y | Y | NA | Y | Y | NA | Y | Good |
| Bang et al.\(^45\) | Y | Y | Y | Y | NR | CD | Y | Y | Y | NR | Y | Y | NR | Y | Good |
| Becker et al.\(^43\) | Y | Y | CD | Y | NR | N | NA | Y | Y | NA | Y | N | NA | N | Fair |
| Castro-Sánchez et al\(^24\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Dapp & Roebers\(^8\) | Y | Y | Y | Y | CD | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Giner-Mira et al.\(^32\) | Y | Y | CD | CD | NR | N | NA | Y | Y | NA | Y | NR | NA | N | Fair |
| Ishihara et al.\(^27\) | Y | Y | N | Y | NR | Y | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Ishihara et al.\(^26\) | Y | Y | N | Y | NR | CD | NA | Y | Y | NA | Y | NR | NA | Y | Fair |
| Ishihara et al.\(^46\) | Y | Y | Y | Y | NR | Y | NA | Y | Y | Y | Y | NR | Y | Y | Good |
| Kristjansson et al.\(^28\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Kristjansson et al.\(^29\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Kwak et al.\(^30\) | Y | Y | Y | Y | CD | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Kyan et al.\(^31\) | Y | Y | CD | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Fair |
| Lambourne et al.\(^32\) | Y | Y | CD | Y | NR | N | NA | Y | Y | NA | Y | NA | Y | NA | Good |
| Lima et al.\(^47\) | Y | Y | CD | Y | NR | Y | Y | Y | Y | Y | NR | CD | Y | Good |
| McPherson et al.\(^33\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Suchert et al.\(^34\) | Y | Y | Y | Y | NR | CD | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Syväoja et al.\(^35\) | Y | Y | Y | Y | NR | CD | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Tremblay et al.\(^36\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Van Dijk et al.\(^28\) | Y | Y | Y | Y | NR | Y | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Van Dijk et al.\(^27\) | Y | Y | Y | Y | NR | Y | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Vedøy et al.\(^48\) | Y | Y | Y | Y | NR | Y | Y | Y | Y | Y | Y | NR | Y | Y | Good |
| Visier-Alfonso et al.\(^2021\)\(^42\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Wang et al.\(^39\) | Y | Y | Y | Y | NR | N | NA | Y | Y | NA | Y | NR | NA | Y | Good |
| Wretman\(^40\) | Y | Y | CD | Y | NR | CD | NA | Y | Y | NA | Y | NA | Y | NR | Good |
| Zhang et al.\(^31\) | Y | Y | Y | Y | Y | CD | NA | Y | Y | NA | Y | NR | NA | Y | Fair |
| Aadland et al.\(^50\) | Y | Y | N | CD | CD | Y | Y | CD | CD | NR | Y | Y | Y | Y | Good |
| Lubans et al.\(^49\) | Y | Y | N | Y | NR | Y | Y | NR | Y | Y | Y | Y | Good |

Abbreviations: CD, Cannot determine; N, No; NA, not applicable; NR, not reported; Y, Yes.
follow a sequence from PA to cardiorespiratory fitness, to cognition and this, in turn, impacts AA, suggesting an indirect association between PA to cognition via cardiorespiratory fitness rather than direct. This hypothesis was tested only in a cross-sectional study. Moreover, cross-sectional nature of reviewed studies prevents from inferring causality and directionality. In addition, it has also been argued that PA may affect AA through specific cognitive domains and not through others; thus, more research to elucidate which specific cognitive functions mediate this association including relationships between physiological variables are needed. Finally, cognitive functions follow different developmental trajectories, and it has been suggested that the associations of each cognitive function with PA and AA may vary depending on age.

### 4.4 Mental well-being as a mediator

Previous literature have hypothesized that PA promote self-efficacy and self-esteem and well-being, and this have an impact on AA. In this study, self-esteem, body-weight image, self-efficacy, the locus of control, and maths self-confidence were found to be possible mediators in the relationship between PA and AA. Stress and behavioral problems were also found to be significant mediators. However, other studies did not support the mediating effect of depression, self-concept, or school related well-being. These results partially support the idea that PA may improve mood and general well-being and, in turn, AA, however, cross-sectional studies did not allow to draw directionality in these relationships and other directions should not be discarded. Moreover, participation in PA improves one’s confidence in their ability to perform specific activities, which generalizes to other domains. However, should be noted that these hypotheses are confirmed by mostly cross-sectional studies and only one longitudinal, whereas one experimental did not support the mediating role of school well-being. In addition, studies in this field are quite heterogeneous in design, methods, measures, and sample size, which does not allow us to draw conclusions. Considering these results, evidence indicates that mental health factors may mediate the effect of PA on AA; however, the mediators studied are miscellaneous, and more cumulative longitudinal and experimental evidence is needed. Questions about which mental health variables mediate this association remains unknown. Moreover, adequate control for age, sex, and socioeconomic characteristics is needed. Another promising mechanism to study in further research is the role of peer relationships, social engagement, and belonging feelings enhanced through PA.

### 4.5 Behavior as a mediator

The behavioral mechanism hypothesis proposes that the positive changes from physical activity are mediated by changes in relevant an associated health behaviors. The reviewed studies do not allow us to draw conclusions. Overall, two cross-sectional studies found that health behaviors and bedtime in girls, however two longitudinal studies found null results regarding classroom behaviors, such as behavioral self-regulation and engagement in maths or leisure time in physical activity. This study suggested that health behaviors, such as hygiene and diet, may mediate the association between PA and AA; however, a lack of research was found. Research in this area may have promising results in future because PA has been suggested to promote changes in health-related behaviors, which affect AA.

For further research, we propose to investigate in longitudinal and cross-sectional studies the role of variables such as dietary patterns, classroom behaviors, social connections, or socialization patterns, which have been hypothesized to be improved by PA and associated with AA.

### 4.6 Statistical approaches

Eighteen out of the 28 studies reviewed used path analysis using SEM and 10 used regression-based mediation. From the 24 paths analyzed by SEM models, 17 reported significant effects, and seven did not reach significant results; from the regression-based mediation, six reported significant effects, and six did not reach significance. Larger sample sizes were used in SEM models than in mediation models (mean sample size: SEM = 5.675; regression-based mediation = 970). Generally, SEM models include larger sample sizes because they test more complex models involving latent variables and many relationships among measured variables. Though a disadvantage of a hierarchical regression approach is that it does not consider errors, thus the existence of measurement errors might result in biased estimation of the mediation effects. SEM allows us to analyze the interrelationships among variables and test hypothesized relationships among constructs (path analytic approach). Therefore, SEM permits us to test a number of interrelationships simultaneously, and to control measurement errors. However, regarding models with observed variables, rather than general models, to test mediation, both approaches show similar results. The duality of methods has been considered in numerous studies. Because the strengths and weaknesses of both approaches have been widely described and
it does not seem clear which is the most advantageous, the use of both approaches in a sensitivity analysis strategy could be an option for the future, using mediation models with longitudinal and intervention data.

4.7 Limitations of this review

This review is subject to limitations. First, the synthesis of the evidence was restricted to narrative descriptions because of the variety of mediators and the way they were analyzed across different studies. Second, the range of statistical approaches used prevented a comparison of the magnitude of effects, and evidence to support arguments for mediation was often reduced to findings from tests of statistical significance. It is important for the future to design studies comparing the magnitude of mediating effects to identify the most influential pathways. Third, the variability in the covariates across studies makes it difficult to draw conclusions; thus, research about significant cofounders and moderators is needed. The review was also limited by publication bias. Most studies provided evidence to support a result for the mediating pathways investigated. It is likely that in studies where previous mediation analyses have been undertaken, only those with statistically significant results have been reported and published. It is also possible that the authors, after testing different models, presented only those results that fit their hypotheses well. Although the fact that half of the studies included in this review showed null results could indicate that selection bias may not be an important concern in this review. The last limitation refers to the nature of the included studies. Most of the included studies had cross-sectional designs, preventing us from establishing causal relationships. Despite the temporality in the direction of the associations proposed in this review is consistently endorsed with the available knowledge about the relationships between PA and AA, the cross-sectional nature of included studies unavoidably prevent us to make causal statements because of temporal ambiguity concerns. Thus, the results may suggest causal relationships that should be judged as preliminary, given the lack of longitudinal designs.

5 Conclusion

There is a relatively small body of research that has formally tested indirect pathways of the relationship between PA and AA. A variety of mediators with high heterogeneity in designs across studies have been found. Data from the reviewed evidence suggest that physiological, cognitive, and psychological variables may underlie the association between PA and AA, but the relationship remains complex because several mediators, moderators, and covariates seem to be involved. In addition, because of methodological limitations inherent in cross-sectional studies, such as measurement imprecision and heterogeneity, research specifically aimed at testing the different plausible paths has been reported so far. However, considering the additional main covariates and moderators that could be involved in the relationship between PA and AA, well-designed follow-up and randomized controlled studies aimed not only to tests the effect of PA in AA, but also to examine the influence of mediators are required, because only these study designs will be able to clarify the specific role of each mediator or moderator without temporal ambiguity concerns.

6 Perspective

Academic achievement is a complex construct influenced by several variables, including physical activity. Previous authors have suggested that different mechanisms may explain the relationship between physical activity to academic achievement. However, to date, there is no integrated model to explain these relationships. This study aimed to identify in the literature the researched mechanisms which explain the relationship between physical activity and academic achievement.

Evidence about physiological, cognitive, psychological or mental well-being, and behavioral variables were found. However, literature was too sparse to draw conclusions and several limitations in included studies should be considered. Thus, we recommend more longitudinal and experimental studies analyzing the mediating effect of mentioned mechanisms between physical activity and academic achievement. In addition, we recommend complex models analyzing together different mechanisms with adequate control variables. This could be of help to design effective physical exercise interventions to improve AA in children and adolescents and to provide recommendations for further studies.

Systematic Review Registration

PROSPERO CRD42020173284.

Conflicts of Interest

The authors have indicated that they have no potential conflicts of interest to disclose.

Author Contributions

Dr Visier-Alfonso designed the search strategy, coordinated, and supervised data collection and draft the manuscript. Dr Sánchez-López designed the search strategy, drafted the initial manuscript, and reviewed and revised the manuscript. Dr Martínez-Vizcaíno contributed to the original concept and designed the study, and critically
reviewed and revised the manuscript. Dr Ruiz-Hermosa carried out the search strategy, collected data, and evaluated selected studies. Drs Álvarez-Bueno and Nieto-López, selected the data collection and risk of bias instruments, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

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**How to cite this article:** Visier-Alfonso ME, Sánchez-López M, Álvarez-Bueno C, Ruiz-Hermosa A, Nieto-López M, Martínez-Vizcaíno V. Mediators between physical activity and academic achievement: A systematic review. *Scand J Med Sci Sports*. 2022;32:452–464. doi:10.1111/sms.14107