Check for updates

Received: 9 May 2023 | Revised: 12 July 2023 | Accepted: 14 August 2023

DOI: 10.1111/sms.14479

REVIEW

WILEY

Acute effect of physical activity on academic outcomes in school-aged youth: A systematic review and multivariate meta-analysis

Adrià Muntaner-Mas[1,2] | **Javier S. Morales**[3,4] | **Óscar Martínez-de-Quel**[5,6] | **David R. Lubans**[7,8,9] | **Antonio García-Hermoso**[10]

[1]GICAFE "Physical Activity and Exercise Sciences Research Group", Faculty of Education, University of Balearic Islands, Palma, Spain

[2]PROFITH "PROmoting FITness and Health Through Physical Activity" Research Group, Sport and Health University Research Institute (iMUDS), Department of Physical Education and Sports, Faculty of Sport Sciences, University of Granada, Granada, Spain

[3]MOVE-IT Research Group, Department of Physical Education, Faculty of Education Sciences, University of Cadiz, Cadiz, Spain

[4]Biomedical Research and Innovation Institute of Cadiz (INiBICA) Research Unit, Puerta del Mar University Hospital, University of Cadiz, Cadiz, Spain

[5]Faculty of Education, Complutense University of Madrid, Madrid, Spain

[6]Faculty of Physical Activity and Sports Sciences-INEF, Technical University of Madrid, Madrid, Spain

[7]Centre for Active Living and Learning, College of Human and Social Futures, University of Newcastle, Callaghan, New South Wales, Australia

[8]Hunter Medical Research Institute, New Lambton Heights, New South Wales, Australia

[9]Faculty of Sport and Health Sciences, University of Jyväskylä, Jyväskylä, Finland

[10]Navarrabiomed, Hospital Universitario de Navarra (HUN), Universidad Pública de Navarra (UPNA), IdiSNA, Pamplona, Spain

Correspondence
Javier S. Morales, MOVE-IT Research Group, University of Cadiz, C. Republica Saharaui s/n, 11519 Puerto Real, Cadiz, Spain.
Email: javier.salvador@uca.es

Funding information
Instituto de Salud Carlos III; Junta de Andalucía; National Health and Medical Research Council Senior Research Fellowship; MCIN/AEI/10.13039/501100011033/FEDER, UE, Grant/Award Number: PID2021-123357OA-100

Abstract

Background: There has been an increase in the number of studies examining the effect of acute and chronic physical activity on academic outcomes in children and adolescents in the last two decades. We aimed to systematically determine the acute effects of physical activity on academic outcomes in school-aged youth and to examine possible moderators.

Methods: We conducted a systematic search using PubMed, Web of Science, SPORTDiscus, and PsycINFO databases (from inception to 11th January 2023) for studies assessing the acute effects of physical activity on academic performance-related outcomes in school-aged youth. A univariate and multivariate meta-analysis was conducted based on a random-effects model with restricted maximum likelihood used to pool the academic outcomes results (Hedge's g).

Results: We included 11 articles (803 children and adolescents [range: 6–16 years]) in the systematic review. Overall, acute physical activity increased academic outcomes (Hedge's $g = 0.35$, 95% CI: 0.20–0.50). Multivariate meta-analyses revealed that physical activity increased academic performance in mathematics (Hedge's $g = 0.29$, 95% CI: 0.16–0.42) and language (Hedge's $g = 0.28$, 95% CI: 0.09–0.47).

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial License, which permits use, distribution and reproduction in any medium, provided the original work is properly cited and is not used for commercial purposes.
© 2023 The Authors. *Scandinavian Journal of Medicine & Science In Sports* published by John Wiley & Sons Ltd.

Only behavior change techniques (Hedge's $g = 0.54$, 95% CI, 0.18–0.90, $p < 0.001$) played a significant role in this relationship.
Conclusions: A single bout of physical activity can improve academic outcomes in school-aged youth, which may serve as a complementary tool for the educational field. However, the observed heterogeneity in the results indicates that we should interpret the findings obtained with caution.

KEYWORDS
academic achievement, active breaks, classroom behavior, motor activity, physically active learning

1 | INTRODUCTION

Physical inactivity is a global problem and less than one in five school-aged youth meet the physical activity recommended guidelines.[1,2] Thus, there is a strong rationale for the public health agenda of promoting physical activity to improve physical, psychological and cognitive health in children and adolescents.[3,4] In the last two decades, there has been an increase in the number of studies examining the effect of acute and chronic physical activity on academic outcomes in children and adolescents. However, previous research from systematic reviews and meta-analyses revealed ambiguous evidence, owing to the fact that not all physical activity interventions result in significant gains in academic outcomes.[5–9] In this scenario, academic outcomes include students' achievement and participation in educational activities (e.g., subject grades, standardized tests and batteries, and classroom behavior). On the other hand, acute physical activity refers to a single bout of physical activity, while chronic physical activity can be defined as repeated bouts over a short- or long-term period.[10] To date, the mechanisms governing the "physical activity–academic performance" relationship are not fully understood, although some potential candidate mechanisms have been proposed.[11]

Acute physical activity interventions can take diverse forms and be implemented in different settings.[12] Thus, depending if the physical activity occurs in schools (during class) or in other settings, in relation to a learning task or academic curriculum, or including cognitive content, they are being referred to differently (e.g. classroom movement behavior, physically active learning, active breaks or acute physical activity). To date, five systematic reviews (three including meta-analyses) have been conducted to examine the acute effects of various forms of physical activity on academic outcomes, showing inconclusive results.[9,12–15]

Relatively little is known about the quantitative (e.g., time and intensity) and qualitative (e.g., type of activity and context of activity) characteristics of physical activity that may enhance or impede the acute effects on academic performance in school-aged youth. While the above evidence has provided a platform to understand the dose–response (duration and intensity) effect of acute physical activity on overall cognitive function, it remains to be elucidated whether such evidence translates to specific domains of academic performance. Additionally, moderators regarding participant-, intervention-, context-, outcome- and study level have been scarcely investigated.[5] Further, the research on these putative moderators has mostly focused on the magnitude of the effects of physical activity on cognitive rather than academic outcomes. For instance, the effect sizes (ES) of an exercise program on brain health outcomes (including academic performance) of 109 children aged 8–11 years with overweight or obesity were virtually consistent across sex, age, and maturation, indicating the absence of a moderating effect at the participant's level.[16] In contrast, at the intervention level the meta-analyses of Ludyga et al.,[17] which include 80 randomized controlled trials, encountered that longer intervention length, longer session duration, and coordinative exercises demonstrated greater advantages of exercise on cognitive function. Another reasonable idea at the context level is that the place (school vs. laboratory settings) of the acute physical activity intervention may moderate the magnitude of the effects.[18] In this context, behavior change techniques are approaches for influencing and modifying individual behaviors during physical activity interventions to improve outcomes.[19] The behavior change techniques that have consistently shown promising results in physical activity interventions are goal setting, self-monitoring, intention formation, and review of behavioral goals.[20,21] In acute studies these techniques may moderate the effectiveness of physical activity interventions by influencing participants' motivation, self-efficacy, social support, and engagement.[22] However, evidence of the moderation effect of behavior change techniques on academic outcomes is

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

scarce and necessitates further exploration. Collectively, deciphering if acute physical activity interventions are equally effective at influencing academic performance regarding certain mediators at different levels remains to be clarified.

The primary aim of our systematic review and meta-analysis was to analyze the effects of acute bouts of physical activity on academic outcomes in children and adolescents. Our secondary aim was to determine potential quantitative (e.g., duration and intensity) and qualitative (e.g., setting) moderators of effects.

2 | METHODS

2.1 | Protocol and registration

The design, conduct and reporting of our systematic review and meta-analysis conform to the Cochrane Handbook for Systematic Reviews of Interventions, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) and the PERSiST (implementing Prisma in Exercise, Rehabilitation, Sport medicine and SporTs science) guidance.[23,24] Our review protocol was registered in PROSPERO (CRD42022355267).

2.2 | Search strategy

We conducted a systematic search in the following electronic databases: PubMed, Web of Science, SPORTDiscus and PsycINFO (with no restriction on the starting date and up to January 11th, 2023). Two reviewers (AM-M and JSM) independently searched articles published in Spanish and English, supplemented by a manual search, and retrospectively included references if necessary. Our keyword search strategy was based on the PICOS criteria and key search terms were pooled into three themes before being combined for the final search.

Based on the PICOS criteria, studies were identified using all possible combinations of the following groups of search terms: (a) "child*" OR "adolesc*" OR "young*" OR "youth" OR "student*" OR "teena*"; (b) "maths*" OR "spell*" OR "read*" OR "grade point average" OR "school grade" OR "numeracy" OR "academic performance" OR "academic achievement" OR "academic behavior" OR "classroom behavior" OR "time on task"; (c) "active breaks" OR "single bouts" OR "acute exercise" OR "acute physical activity" OR "classroom movement breaks" OR "physically active learning" OR "classroom activity breaks". We adapted the search terms for each database in combination with database-specific filters. Titles, abstracts, and full texts were assessed for eligibility for potential inclusion. The complete equation search is provided in Tables S2–S5.

2.3 | Selection criteria

Studies were eligible for inclusion if they met all the following criteria (PICOS criteria)[23]: (i) participants: children and adolescents aged 5–17 years old; (ii) intervention: acute physical activity (we set the threshold of only one session of physical activity as "acute"); (iii) comparison: no exercise, rest or any sedentary activity; (iv) outcome: pre-post changes in academic performance (Table S1 shows the academic performance constructs and categories included); and (v) study design: between-participants pre-post comparison, within-participants crossover post comparison, or within-participants crossover pre-post comparison.[10] Searching was restricted to articles published in English- and Spanish-language peer-reviewed journals. Exclusion criteria were studies conducted in populations of other ages, studies with no control session, gray literature, and qualitative and case studies.

2.4 | Selection process

After identifying eligible studies, we used Mendeley (version for Windows 10, Elsevier) to remove duplicate studies. Two authors (AM-M and JSM) conducted the selection process independently and screened every title and abstract to identify potentially relevant articles to be reviewed in the full-text phase. A third researcher (OMQ) participated to resolve any discrepancies.

2.5 | Data collection process

The following information on the included studies was extracted: (i) the country in which the study was conducted; (ii) information regarding the study population (sample size, age, sex); (iii) intervention features (e.g., setting, experimental design, study quality, number of experimental conditions, session length, time of the day, behavior change techniques, type of physical activity, physical activity duration, physical activity intensity, and time of test administration); (iv) academic performance tasks (e.g., school grades, classroom behavior); (v) main results; and (vi) pre-post changes mean and standard deviation in academic performance outcomes for experimental and control groups. When the standard error was reported instead of the standard deviation, the latter was obtained through the formula of Altman & Bland.[25] If needed, data from figures were extracted

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

using specific software (Web Plot Digitizer v4.5). We contacted the corresponding author of the studies that did not report the required data. The data were then independently checked by a second author.

2.6 | Quality of evidence

The Physiotherapy Evidence Database (PEDro) was used to appraise each study critically.[26] This tool consists of 11 domains and was designed to measure the methodological quality of each trial (criteria are detailed in Table S6). Two reviewers independently assessed the risk of bias in the included reviews (AM-M and JSM). Disagreements were resolved through discussion with a third reviewer (OM-Q).

2.7 | Data analysis

Univariate analyses were carried out with STATA software using *admetan* and *lfk* modules (v17; StataCorp, College Station). Random-effect models with restricted maximum likelihood were used. The ES was expressed as Hedge's *g* to correct for possible small sample bias.

An overall effect of acute physical activity on academic outcomes was determined. Also, separate pooled analyses were conducted on the following academic performance outcomes based on the available data: mathematics, language, and classroom behavior. To avoid double-counting and following the Cochrane Handbook recommendations, when a study included more than two arms in comparison with a control group, we halved the number of participants in the control group for each of the comparisons.[27] Heterogeneity across studies was calculated using the inconsistency index (I^2), derived from the Cochran Q statistic: negligible heterogeneity, 0%–40%; moderate heterogeneity, 30%–60%; substantial heterogeneity, 50%–90%; and considerable heterogeneity, 75%–100%.[28] Lastly, small-study effects and publication bias were examined using the Doi plot and the Luis Furuya-Kanamori (LFK) index.[29] LFK values beyond ±1 are considered to be indicative of minor asymmetry; values ±2 indicate major asymmetry and suggest the presence of publication bias.

Whenever possible, sub-group analyses were used according to the type of skill in mathematics (i.e., math tests and arithmetic tests) and language (i.e., spelling, reading, and sentence comprehension), age (children and adolescents), setting (school or other), experimental design (within or between design), study design (crossover vs. others), number of experimental conditions (≤2 or >2), behavior change techniques (yes or no), type of physical activity (aerobic or combined), physical activity duration (<20 min or ≥20 min), physical activity intensity (moderate-to-vigorous or other intensities), time of test administration (<20 min or ≥20 min after exercise). We considered moderation when the difference between groups was $p \leq 0.10$.[30]

We conducted a sensitivity analysis to assess the robustness of the summary estimates and to determine whether a particular study accounted for the inconsistency. To examine the effects of each result from each study on the overall results, results were analyzed with each study removed from the model once. Additional random-effects multivariate meta-analysis with restricted maximum likelihood was also carried out using the STATA procedure *mvmeta*.[31] Multivariate meta-analysis is different from pairwise (univariate) meta-analysis as it allows for multiple outcomes to be included by considering the correlation between outcomes (i.e., in our study the correlations among mathematics performance, language performance and behavior control). Based on prior research, we adopted a within-study correlation of 0.42 for each multivariate meta-analysis.[32]

3 | RESULTS

3.1 | Study selection

From the retrieved articles, 11 studies were included in the systematic review and meta-analyses (Figure 1; articles removed and reasons for exclusion are shown in Table S7). This included 803 participants in total (43% female, although two studies did not specify the sex of the participants[33,34]). The characteristics of the different studies are shown in Table 1 and Table S8.[33–43]

3.2 | Participants

Sample sizes ranged from 18 to 244 participants, with an age range of 6 to 16 years. One study included 50% of the sample size of children with attention deficit/hyperactivity disorder.[43]

3.3 | Intervention characteristics

The physical activity interventions lasted from four to 30 min,[35,42] with 20 min being the most common bout duration.[36,39–41,44] Physical activity modality differed across studies yet with most ($n=8$) applying an acute aerobic exercise.[34,36,38–43] A smaller number of studies consisted of strength exercises,[39] a combination of both

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

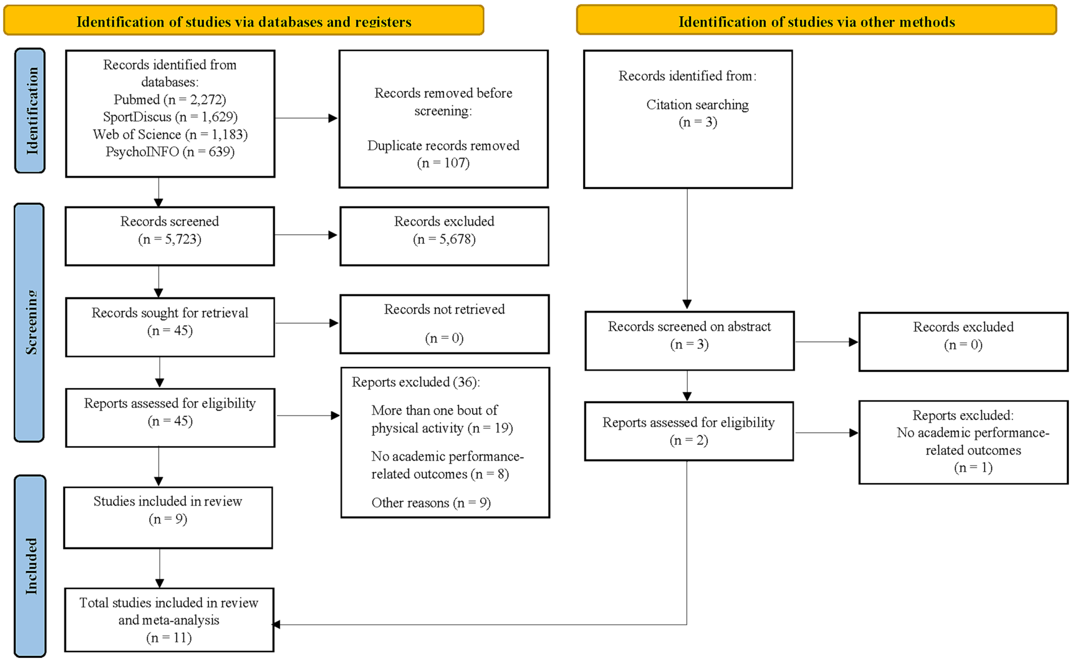

FIGURE 1 PRISMA flow diagram of literature search.

aerobic and strength exercises[33,37] or high-intensity interval training.[35] The intensity was also heterogeneous, ranging from 50% of maximum heart rate (HR_{max}) or reserve to 85% of HR_{max}. In one study,[41] participants were asked to achieve a heart rate of 150 beats per minute. Four of the included studies categorized the intensity of the intervention as vigorous, moderate, low-moderate or moderate-vigorous physical activity but without specifying to which specific intensity (i.e., % HR_{max}) these categories corresponded.[33,35,37,38]

3.4 | Data synthesis

Table 2 shows quantitative data of the studies included in the systematic review and meta-analysis. Overall, our meta-analysis demonstrated that acute physical activity increased academic performance (Hedge's $g=0.35$, 95% CI, 0.20–0.50, $p<0.001$, $I^2=53.96\%$) and no asymmetry suggestive of small-study effects was observed (LFK index = 1.10) (Figure S1). Regarding moderators, programs that included behavior change techniques resulted in larger effects (Hedge's $g=0.54$, 95% CI, 0.18–0.90, $p<0.001$, $I^2=78.59\%$) compared with programs that did not (Hedge's $g=0.23$, 95% CI, 0.10–0.36, $p<0.001$, $I^2=0\%$). However, the other moderators showed no statistical significance (i.e., age, setting, experimental and study design, number of experimental conditions, type, duration and intensity of physical activity, and time of test administration). Finally, the sensitivity analyses indicated no modifications in the results after removing one study at a time (Figure S2).

3.4.1 | Mathematics performance

Nine studies assessed the effects of acute physical activity on mathematics performance through different tasks such as math tests, the Wechsler individual achievement test—3rd edition, the Wide Range Achievement Test (WRAT)-3 and 4, and The New York State Testing Program.[33,34,36,37,39–43] Our univariate and multivariate meta-analysis showed that acute physical activity interventions were associated with improved mathematics performance (univariate: Hedge's $g=0.31$, 95% CI, 0.18–0.44, $p<0.001$, $I^2=0\%$; multivariate: Hedge's $g=0.29$, 95% CI, 0.16–0.42, $p<0.001$, $I^2=28.92\%$). Regarding sub-group meta-analysis, a significant increase was observed in math tests (Hedge's $g=0.34$, 95% CI, 0.19–0.48, $p<0.001$, $I^2=0\%$), but not in arithmetic tests (Hedge's $g=0.18$, 95% CI, −0.12 to 0.48, $p=0.237$, $I^2=0\%$) ($p=0.35$ between groups) (Table 3).

3.4.2 | Language performance

Three studies assessed the effects of acute physical activity on language performance through different tests such as WRAT-3 and WRAT-4.[36,40,43] Acute physical activity favored an increase in this domain (univariate: Hedge's

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 Descriptive characteristics of included studies ($n = 11$).

Study (year) and country	Demographic characteristics of the sample (n, sex, age [years])	Experimental design	Intensity	Type of physical activity	Session length	Outcomes (tests)	Results
Broad et al. (2021). Canada	-EG1 (morning): 35 (13 female) 6 ± 1 year -EG2 (afternoon): 35 (13 female) 6 ± 1 year -EG3 (morning and afternoon): 35 (13 female) 6 ± 1 year -CG: 35 (13 female) 6 ± 1	Within-subjects crossover post-comparison	Vigorous	Tabata (20 sec of exercise interspersed by 10 sec of rest, repeated eight times)	4 min	- Behavioral control (TOT and off-task behavior)	-Improvement in EG1, EG2 and EG3 compared to CG: ↑ TOT -Improvement in the EG1 compared to EG2, EG3 and CG: ↑ off-task motor and off-task verbal behavior -Improvement in the EG2 compared EG1, EG3 and CG: ↑ off-task passive behavior
Duncan et al. (2014). United Kingdom	-EG1: 18 (9 female) 9.8 ± 1.4 years - EG2: 18 (9 female) 9.8 ± 1.4 years - CG: 18 (9 female) 9.8 ± 1.4 years	Within-subjects crossover post-comparison	- 50% HRR (EG1) - 75% HRR (EG2)	Aerobic exercise (cycling ergometer)	20 min	- Reading comprehension, spelling, arithmetic and sentence comprehension (WRAT4)	-Improvement in EG1 and EG2 compared to CG: ↑ spelling -Improvement in CG compared to EG1 and EG2: ↑ arithmetic -No difference in the outcomes of interest between EG1 and EG2
Fiorilli et al. (2021). Italy	- EG: 51 (25 female) 9.6 ± 0.8 years - CG: 50 (22 female) 9.7 ± 0.8	Between-subjects pre-and post-test	MVPA	Strength and aerobic exercises	15 min	- Mathematics performance (math test)	-Improvement in EG compared to CG: ↑ mathematics performance
Grieco et al. (2016). USA	- EG1 (LMPA): 81 (38 female) 9.8 ± 0.8 - EG2 (MVPA): 76 (43 female) 9.1 ± 0.9 - CG (sedentary academic game): 87 (42 female) 9.2 ± 1.0	Within-subjects pre-and post-test	LMPA (EG1) MVPA (EG2)	Aerobic exercises	10–15 min	- Behavior control (TOT)	-No difference in the outcome of interest between groups
Harveson et al. (2019). USA	- EG1 (aerobic): 63 (6 female) 13.7 ± 0.5 - EG2 (strength): 63 (6 female) 13.7 ± 0.5 - CG: 63 (6 female) 13.7 ± 0.5	Within-subjects crossover post-comparison	- 50%–60% HR_{max} (EG1) - N/R (EG2)	Aerobic exercises: walking or jogging (EG1) Strength exercises: squat, lunge, push-up, band pull-down, band row, and overhead press (EG2)	20 min	- Mathematics performance (math test)	-Improvement in EG2 compared to CG: ↑ mathematics performance -No difference in the outcome of interest between EG1 and CG
Hillman et al. (2009). USA	-EG: 20 (8 female) 9.5 ± 0.5 years -CG: 20 (8 female) 9.5 ± 0.5 years	Within-subjects pre-and post-test	60% HR_{max}	Aerobic exercise: walking	20 min	- Reading comprehension, spelling and arithmetic (WRAT3)	-Improvement in EG compared to CG: ↑ reading comprehension

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 (Continued)

Study (year) and country	Demographic characteristics of the sample (n, sex, age [years])	Experimental design	Intensity	Type of physical activity	Session length	Outcomes (tests)	Results
Howie et al. (2015). USA	-EG1: 96 (62 female) Range: 9–12 years -EG2: 96 (N/R female) Range: 9–12 years -EG3: 96 (N/R female) Range: 9–12 years -CG: 96 (N/R female) Range: 9–12 years	Within-subjects pre-and post-test	MVPA (150 bpm)	Aerobic exercise: jumping and running	- 5 min (EG1) - 10 min (EG2) - 20 min (EG3)	- Mathematics performance (math test)	-Improvement in EG2 and EG3 compared to CG: ↑ mathematics performance
Kawabata et al. (2021). Singapore	-EG1 (fasting and exercise): 20 (14 female) 16.1 ± 0.9 -EG2 (breakfast and exercise): 20 (17 female) 15.9 ± 1.2 -CG1 (fasting and sedentary): 21 (17 female) 16.0 ± 1.3 -CG2 (breakfast and sedentary): 21 (16 female) 16.1 ± 0.8	Between-subjects pre-and post-test	60% VO_{2peak}	Aerobic (running) and coordinative exercises	30 min	- Mathematic and oral word fluency (WIAT-III)	-Improvement in EG2 compared to CG1: ↑ mathematics performance -Improvement in EG2 compared to CG1 and EG1: ↑ mathematics speed
Mavilidi et al. (2020). Australia	-EG1 (low anxious): 13 (N/R female) Range: 11–12 years -EG2 (high anxious): 20 (N/R female) Range: 11–12 years -CG1 (low anxious): 14 (N/R female) Range: 11–12 years -CG2 (high anxious): 21 (N/R female) Range: 11–12 years	Between-subjects post-comparison	Moderate	Aerobic and strength exercises (push-ups, star jumps, penguin movements, burpees, and running on the spot)	10 min	- Mathematics performance (math test)	-No difference in the outcome of interest between groups
Phillips et al. (2015). USA	-EG: 36 (N/R female) Range: 14–15 years -CG: 36 (N/R female) Range: 14–15 years	Within-subjects crossover post-comparison	70%–85% HR_{max}	Aerobic exercises (Line Jumps, Ladder Run, Hurdles, Step Ups, High Knees, Shuttle Drills, Z Pattern Run, Jump Rope, Jumping Jacks)	20 min	- Mathematics performance (The New York State Testing Program)	-Improvement in EG compared to CG: ↑ mathematics performance when the test was administered 30 minutes post-exercise (compared with 45 minutes post-exercise, 30- and 45-minutes post-sedentary)
Pontifex et al. (2013). USA	-EG: 40* (12 female) Range: 8–10 years -CG: 40* (12 female) Range: 8–10 years *20 children (6 female) with ADHD	Within-subjects crossover post-comparison	60%–75% HR_{max}	Aerobic exercises: running/walking	20 min	- Reading comprehension, spelling and mathematics performance (WRAT3)	-Improvement in EG compared to CG: ↑ reading comprehension and arithmetic

Abbreviations: ADHD, attention-deficit/hyperactivity disorder; CG, control group; EG, exercise group; HR, heart rate; HRR, heart rate reserve; LMPA, low-moderate PA; MVPA, moderate-vigorous PA; N/R, not reported; PA, physical activity; RCT, randomized controlled trial; TOT, time on task; USA, United States of America; VO_{2peak}, peak oxygen uptake; WIAT-III, the Wechsler individual achievement test—3rd edition; WRAT, the wide range achievement test.

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 Quantitative data of the studies included ($n = 11$).

		Experimental groups		Control group	
Study (year)	Outcome (Test)	*n*	mean ± SD	*n*	mean ± SD
Broad et al. (2021).	Behavior control (TOT)	35 (AM) 35 (PM) 35 (Both)	58.22 ± 7.94* 58.22 ± 7.94* 62.09 ± 8.95*	35	48.24 ± 11.01
Duncan et al. (2014)	Arithmetic test (WRAT4)	18 (LMPA) 18 (MVPA)	88.64 ± 17.65 88.64 ± 21.72	18	95.68 ± 21.72*
	Spelling (WRAT4)	18 (LMPA) 18 (MVPA)	106.88 ± 23.08* 108.48 ± 19.01*	18	97.28 ± 28.51
	Reading comprehension (WRAT4)	18 (LMPA) 18 (MVPA)	109.12 ± 27.15 103.04 ± 28.51	18	103.68 ± 25.80
	Sentence comprehension (WRAT4)	18 (LMPA) 18 (MVPA)	101.39 ± 28.59 103.31 ± 27.24	18	104.92 ± 27.24
Fiorilli et al. (2021)	Mathematics performance (math test)	51	28.75 ± 4.69*	50	25.31 ± 6.25
Grieco et al. (2016)	Behavior control (TOT)	81 (LMPA) 76 (MVPA)	70.4 ± 24.3 82.7 ± 19.6	87	69.3 ± 27.6
Harveson et al. (2019)	Mathematics performance (math test)	63 (aerobic) 63 (strength)	3.82 ± 1.93 3.98 ± 2.50*	63	3.39 ± 1.91
Hillman et al. (2009)	Arithmetic test (WRAT3)	20	115.30 ± 10.99	20	114.60 ± 14.22
	Spelling (WRAT3)	20	112.65 ± 9.96	20	111.00 ± 10.86
	Reading comprehension (WRAT3)	20	116.05 ± 9.52*	20	110.70 ± 8.48
Howie et al. (2015)	Mathematics performance (math test)	94 (EG1) 94 (EG2) 94 (EG3)	25.1 ± 0.5 25.4 ± 0.5 25.5 ± 0.5	94	24.3 ± 0.5
Kawabata et al. (2021)	Mathematics performance (WIAT-III)	20 (fasting and exercise)	52.62 ± 6.03	21 (fasting and sedentary)	50.14 ± 5.90
		20 (breakfast and exercise)	49.41 ± 6.83	21 (breakfast and sedentary)	49.81 ± 8.77
Mavilidi et al. (2020)	Mathematics performance (math test)	13 (low anxious) 20 (high anxious)	5.23 ± 1.64 4 ± 1.39	14 (low anxious) 21 (high anxious)	5 ± 1.85 4.12 ± 1.47
Phillips et al. (2015)	Mathematics performance (The New York State Testing Program)	44 (male post PA 30 min)	6.11 ± 2.2*	44 (male post sedentary 30 min)	4.7 ± 1.92
		44 (male post PA 45 min)	4.57 ± 1.9	44 (male post sedentary 45 min)	4.34 ± 1.92
		28 (female post PA 30 min)	5.18 ± 2.52*	28 (female post sedentary 30 min)	3.43 ± 2.21
		28 (female post PA 45 min)	3.89 ± 1.81	28 (female post sedentary 45 min)	3.57 ± 1.52
Pontifex et al. (2013)	Arithmetic test (WRAT3)	40	112.58 ± 17.06*	40	109.78 ± 19.53
	Spelling (WRAT3)	40	108.43 ± 14.35	40	108.67 ± 13.40
	Reading comprehension (WRAT3)	40	115.18 ± 14.04*	40	110.12 ± 11.57

Abbreviations: LMPA, low-moderate PA; MVPA, moderate-vigorous PA; PA, physical activity; SD, standard deviation; TOT, time on task; WIAT-III, the Wechsler individual achievement test—3rd edition; WRAT, the wide range achievement test.

*Significant differences between groups.

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 3 Pooled effect sizes and 95% confidence intervals (CI) for main and sub- domain outcomes included in the study from univariate and multivariate analyses.

	Hedge's *g*	95% CI	*p*	I^2
Univariate				
Mathematics performance	0.31	0.18 to 0.44	<0.001	0
Maths tests	0.34	0.19 to 0.48	<0.001	0
Arithmetic tests	0.18	−0.12 to 0.48	0.237	0
Language performance	0.21	0.04 to 0.38	0.020	0
Spelling	0.08	−0.25 to 0.41	0.604	0
Reading	0.41	0.07 to 0.76	0.018	0
Sentence comprehension	−0.09	−0.90 to 0.71	0.821	0
Multivariate				
Mathematics performance*	0.29	0.16 to 0.42	<0.001	28.92
Language performance	0.28	0.09 to 0.47	0.004	47.87
Spelling	0.08	−0.24 to 0.41	0.610	0
Reading	0.34	−0.14 to 0.82	0.161	11.59
Sentence comprehension	−0.08	−0.74 to 0.57	0.794	0.53

*No studies included both domains of mathematics performance, for this reason we did not performed a multivariate analysis.

$g=0.21$, 95% CI, 0.04–0.38, $p=0.020$, $I^2=0\%$; multivariate: Hedge's $g=0.28$, 95% CI, 0.09–0.47, $p=0.004$, $I^2=47.87\%$). Regarding sub-group univariate meta-analysis, a significant increase was observed in reading performance (Hedge's $g=0.41$, 95% CI, 0.07–0.76, $p=0.018$, $I^2=0\%$), but not in sentence comprehension (Hedge's $g=-0.09$, 95% CI, −0.90 to 0.71, $p=0.821$, $I^2=0\%$), and spelling performance (Hedge's $g=0.08$, 95% CI, −0.25 to 0.41, $p=0.604$, $I^2=0\%$) (Table 4). In contrast and using the multivariate meta-analysis, significance disappears in the reading domain (Hedge's $g=0.34$, 95% CI, −0.14 to 0.82, $p=0.161$, $I^2=11.59\%$).

3.4.3 | Behavior control

Only two studies assessed the effects of acute physical activity on behavior control.[35,38] Both assessed time-on-task and one study evaluated three types of off-task (motor, verbal, passive) behavior.[35] Broad et al.[35] found that acute physical activity at different times within the school day (morning, afternoon, or both) increased on-task behavior compared to control. Furthermore, acute physical activity in the morning increased off-task motor and off-task verbal behavior compared to the afternoon, morning and afternoon, and control. However, acute physical activity in the afternoon increased off-task passive behavior compared to the morning, morning and afternoon, and control.

3.5 | Quality of evidence

The quality of the included studies was overall good (average PEDro score of 5; Table S6). Six out of 11 studies had good quality (total score of 5–7), and the remaining studies were deemed to have poor quality (total score ≤4).[37–42]

4 | DISCUSSION

Our systematic review and meta-analysis aimed to examine the acute effects of physical activity on academic performance in children and adolescents. Our meta-analysis identified 11 studies and suggested that acute physical activity can produce small but significant improvements in overall academic outcomes (Hedge's $g=0.35$), mathematics performance (Hedge's $g=0.29$) and language performance (Hedge's $g=0.28$). Additionally, a secondary aim of our study was to examine key potential moderators. Our findings showed that using behavior change techniques was associated with larger effects. However, we must interpret the present results with caution since there is heterogeneity both in the interventions (i.e., duration, intensity) and in the obtained outcomes (i.e., I^2 values).

The current research rises upon evidence from previous reviews and addresses the transient effects of physical activity on specific academic performance domains, such as mathematics performance, reading performance, and classroom behavior.[9,12–15] Specifically, in the review of Haverkamp et al.[15] only one study (assessing academic performance) was included and the authors did not conduct a meta-analysis. Furthermore, de Greeff et al.[9] did not find a significant effect of three acute physical activity interventions on academic performance. Mavilidi et al.[12] found a large ES of active breaks in behavioral control (including five studies with

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4 Subgroup analysis according to moderators.

	Hedge's g	95% CI	p	I^2	p*
Age					
Children	0.39	0.15–0.62	<0.001	73.20	0.599
Adolescents	0.30	0.11–0.50	0.002	0	
Setting					
School	0.46	0.14–0.79	0.001	79.39	0.238
Others	0.25	0.11–0.39	0.001	0	
Experimental design					
Within	0.37	0.18–0.56	<0.001	63.52	0.680
Between	0.28	−0.08 to 0.65	0.123	54.27	
Study quality					
Crossover	0.44	0.06–0.81	0.007	84.94	0.566
Others	0.32	0.17–0.46	<0.001	0	
Number of experimental conditions					
≤2	0.35	0.20–0.50	<0.001	12.65	0.956
>2	0.36	0.02–0.69	0.017	79.66	
Behavior change techniques					
Yes	0.54	0.18–0.90	<0.001	78.59	0.093
No	0.23	0.10–0.36	<0.001	0	
Type of physical activity					
Aerobic	0.23	0.09–0.38	0.002	0	0.196
Combined	0.44	0.16–0.72	<0.001	73.82	
Physical activity duration					
<20 min	0.52	0.12–0.91	0.003	82.23	0.204
≥20 min	0.25	0.12–0.38	<0.001	0	
Physical activity intensity					
Moderate-to-vigorous	0.37	0.19–0.55	<0.001	29.30	0.840
Other intensities	0.34	0.06–0.61	0.007	73.91	
Time of test administration					
< 20 min after exercise	0.45	0.07–0.82	0.005	84.20	0.486
≥ 20 min after exercise	0.30	0.16–0.45	<0.001	0	

Abbreviation: CI, confidence interval.

*Differences between group.

chronic and/or acute physical activity). However, behavioral control could not be meta-analyzed in our study due to the low number of studies available evaluating the effect of acute physical activity on this outcome. Watson et al.[13] showed that classroom-based physical activity had a moderate ES on improving behavioral control (including four studies). Daly-Smith et al.[14] concluded that physically active lessons or classroom-based physical activity (including 10 studies) improved classroom behavior. In sum, the evidence from these reviews did not explore the effects of acute physical activity on other academic performance domains (e.g., arithmetic, spelling). Also, all these reviews focused exclusively on examining one or two of these forms of physical activity at the same time (classroom movement behavior, acute physically active learning, active breaks or acute physical activity). Our study fills these gaps in the evidence by addressing a previously unexplored multivariate meta-analysis of various moderators that, to the best of our knowledge, had not been done before.

Active breaks were the predominant form of physical activity used in the studies included in our review (10

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

out of 11). These interventions are characterized by the fact that they take into account neither the embodiment (physical activity is not related to a learning task) nor the integration (there is no temporal overlap between movements and the learning task) concepts.[45] Although we endorse the potential benefits of the embodied learning by techniques as gesturing or integrating the academic content with a meaningful bodily activity,[46] our findings suggested a complementary message such that human movement with minimal cognitive load may also improve academic performance.[47] Additionally, within a school context, timing and planning have been recognized as key common barriers to implementing movement-based interventions.[48] Aligned with this, interventions involving changes in pedagogical styles seem to be more feasible for real-world implementation than changes in the curriculum/academic content.[49] Altogether, it makes sense to think that active break forms—rather than other types of acute physical activity strategies—may be an appealing strategy for an educational context.

Another difference to account for is that we set the threshold of a single session of physical activity to consider intervention as "acute", but Mavilidi et al.[12] set this threshold at <3 weeks. Furthermore, Daly-Smith et al.[14] included interventions that took place only in a school setting whereas we also include those interventions delivered in other settings. Therefore, our findings showed that a single bout of physical activity, whether implemented inside or outside the school setting, can lead to improvements in academic performance. In summary, our study added meaningful contextual nuances that may be especially relevant for the adoption and implementation of acute physical activity interventions in real-world conditions.[50]

The question of what dose of acute physical activity is needed to elicit beneficial effects on academic performance is not easy to approach. Our analyses suggest that no specific duration was associated with greater changes in academic performance outcomes. Most previous studies have tested the effects of activity breaks lasting from 10 to 20 min in duration. Notwithstanding, our results indicate that improvements in academic performance can occur with as little as a 4-min "dose" of physical activity.[35] In terms of intensity, the studies reviewed used a range from 50% to 85% of HR_{max}, with moderate intensity being the most commonly used. Likewise, our meta-regression analyses indicate that physical activity intensity was not associated with academic performance outcomes. At this point, it is worth speculating on the impact of intensity on cognitive outcomes. Chang et al.[51] analyzed the magnitude of the intensity effect on outcomes accounting by time elapsed between physical activity and academic performance tests. Interestingly, their findings suggested the idea that higher intensity is necessary to temporarily maximize the effects of physical activity on academic performance. Our results on duration and intensity may altogether support the catecholamine hypothesis that moderate intensity and short to moderate duration (10–20 min) elicit catecholamine release.[52] An alternative idea is that intensity may play a task-dependent role, such that low-load cognitive tasks may benefit more from vigorous physical activity intensities,[53] although this speculation is far from being understood.[54]

Our analyses also showed that the use of behavior change techniques in acute physical activity interventions is important. Note that limited knowledge is available regarding the manipulation of behaviors in physical activity interventions for youth. In this sense, Anselma et al.[22] found in their systematic review that demonstration, practice and providing instructions on how to perform a behavior were the most commonly applied and effective behavior change techniques in children from lower socioeconomic environments. Contrarily, the effectiveness of behavioral techniques in physical activity interventions for adults has been more explored.[20,21] Collectively, more knowledge of which techniques is effective for which target groups, could enrich the acute physical interventions field, especially for improving academic performance.

More research is needed on the quantitative and qualitative characteristics of acute physical activity before claims can be made about the specificity or generality of its effects on academic performance. However, some implications for educational practice can be speculated. Our findings demonstrate the acute benefits of embedding physical activity during the school day. Within the school context, it would be desirable to integrate physical activity into regular classrooms and in coherence with academic content, however, far from achieving this, strategies with low relevance, and low integration to learning—such as active breaks— may be worthy of use at this time. An example of the potential academic benefits of reallocating curriculum time to physical activity with active breaks is the study of Mavilidi et al.,[55] which was a sub-study of the Burn 2 Learn (B2L) cluster randomized controlled trial. The intervention involved teacher-facilitated high-intensity activity breaks delivered during lesson time (N = 211 students). The B2L intervention was successful in improving students' on-task behavior (ES = 0.43). According to our results, we recommend acute physical activity interventions starting with doses of at least 10 min of moderate intensity (as a minimum) and the use of behavior change techniques, but this advice should be carefully considered. Pontifex et al.[43] found that a single bout of moderate aerobic exercise improved reading comprehension and arithmetic skills in children with attention-deficit/hyperactivity

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

disorder. In this sense, despite the evidence being incipient, it is plausible to think that acute physical activity interventions may also be relevant for children with neurodevelopmental disorders.[56]

4.1 | Strength and limitations

Some limitations should be noted before concluding. The interpretation of our moderation analyses is limited by third-order causation in meta-analyses. Also, there was considerable heterogeneity of effects, and effects may not be consistent across different groups (e.g., special populations) and under certain circumstances (e.g., the way the activity breaks were delivered). Second, due to the small number of studies included in our review, it is likely that our meta-regression analyses were underpowered to detect significant moderator effects. Third, we found considerable variability in critical design features, especially the study design, which should be accounted for. Finally, there was little consistency in the measurement of academic outcomes, which may have contributed to the heterogeneity in the meta-analyses. Contrary, this is the first systematic review that analyses specific moderators and considers all types of acute physical activity interventions.

In sum, our findings suggest that a single bout of physical activity can support overall and specific domains of academic performance (mathematics and language) in school-aged youth. Only 11 studies that met the inclusion criteria were included in this meta-analysis, indicating that further research is needed to fully comprehend the mechanisms and reasons behind the observed positive influence of physical activity on academic outcomes.

5 | PERSPECTIVES

Acute physical activity interventions starting with doses of at least 10 min of moderate intensity (as a minimum) and using behavior change techniques can elicit improvements in academic performance among school-aged youth. Prompt rewards, feedback on performance and provided instruction were behavior change techniques commonly used in the included studies and may be suitable to apply in future investigations. Although the research discussed in this meta-analysis can provide some guidance in this field, further high-quality research is required to decipher the optimal dose of physical activity, as the mechanistic factors that are beyond its effects.

AUTHOR CONTRIBUTIONS

Adrià Muntaner-Mas contributed to study design. Adrià Muntaner-Mas, Javier S Morales and Óscar Martínez-de-Quel contributed to the systematic search, screening, and data abstraction. AGH contributed to statistical analysis. Antonio García-Hermoso, Adrià Muntaner-Mas and Javier S Morales contributed to data interpretation. Antonio García-Hermoso, Adrià Muntaner-Mas, Javier S Morales, and Óscar Martínez-de-Quel contributed to writing the first draft. All the authors revised and approved the manuscript.

FUNDING INFORMATION

This work was supported by a postdoctoral contract granted by Junta de Andalucía (PAIDI 2020, POSTDOC_21_00725 to JSM). This research was funded by MCIN/ AEI /10.13039/501100011033/ and by FEDER Una manera de hacer Europa under grant number PID2021-123357OA-I00. AGH is a Miguel Servet Fellow (Instituto de Salud Carlos III – CP18/0150). DRL is funded by a National Health and Medical Research Council Senior Research Fellowship (APP1154507).

CONFLICT OF INTEREST STATEMENT

The Authors have no conflict of interest to declare. The material presented in this manuscript is original and it has not been submitted for publication elsewhere.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Adrià Muntaner-Mas https://orcid.org/0000-0002-4083-5948
Javier S. Morales https://orcid.org/0000-0002-3255-3246
Óscar Martínez-de-Quel https://orcid.org/0000-0003-0992-4149
Antonio García-Hermoso https://orcid.org/0000-0002-1397-7182

REFERENCES

1. Guthold R, Stevens GA, Riley LM, Bull FC. Global trends in insufficient physical activity among adolescents: a pooled analysis of 298 population-based surveys with 1.6 million participants. *Lancet Child Adolesc Heal*. 2020;4:23-35.
2. Garcia-Hermoso A, López-Gil JF, Ramírez-Vélez R, Alonso-Martínez AM, Izquierdo M, Ezzatvar Y. Adherence to aerobic and muscle-strengthening activities guidelines: a systematic review and meta-analysis of 3.3 million participants across 31 countries. *Br J Sports Med*. 2022;bjsports-2022-106189;57:229.
3. Bull FC, Al-Ansari SS, Biddle S, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. *Br J Sports Med*. 2020;54:1451-1462.
4. Chaput JP, Willumsen J, Bull F, et al. 2020 WHO guidelines on physical activity and sedentary behaviour for children and

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

adolescents aged 5–17 years: summary of the evidence. *Int J Behav Nutr Phys Act*. 2020;17:141.
5. Pesce C, Vazou S, Benzing V, et al. Effects of chronic physical activity on cognition across the lifespan: a systematic meta-review of randomized controlled trials and realist synthesis of contextualized mechanisms. *Int Rev Sport Exerc Psychol*. 2021;1-39. doi:10.1080/1750984X.2021.1929404
6. Vorkapic CF, Alves H, Araujo L, et al. Does physical activity improve cognition and academic performance in children? A systematic review of randomized controlled trials. *Neuropsychobiology*. 2021;80:454-482.
7. Singh AS, Saliasi E, Van Den Berg V, et al. Effects of physical activity interventions on cognitive and academic performance in children and adolescents: a novel combination of a systematic review and recommendations from an expert panel. *Br J Sports Med*. 2019;53:640-647.
8. Donnelly JE, Hillman CH, Castelli D, et al. Physical activity, fitness, cognitive function, and academic achievement in children: a systematic review. *Med Sci Sports Exerc*. 2016;48:1197-1222.
9. de Greeff JW, Bosker RJ, Oosterlaan J, Visscher C, Hartman E. Effects of physical activity on executive functions, attention and academic performance in preadolescent children: a meta-analysis. *J Sci Med Sport*. 2018;21:501-507.
10. Pontifex MB, McGowan AL, Chandler MC, et al. A primer on investigating the after effects of acute bouts of physical activity on cognition. *Psychol Sport Exerc*. 2019;40:1-22.
11. 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.
12. Mavilidi MF, Pesce C, Benzing V, et al. Meta-analysis of movement-based interventions to aid academic and behavioral outcomes: a taxonomy of relevance and integration. *Educ Res Rev*. 2022;37:100478.
13. Watson A, Timperio A, Brown H, Best K, Hesketh KD. Effect of classroom-based physical activity interventions on academic and physical activity outcomes: a systematic review and meta-analysis. *Int J Behav Nutr Phys Act*. 2017;14:114.
14. Daly-Smith AJ, Zwolinsky S, McKenna J, Tomporowski PD, Defeyter MA, Manley A. Systematic review of acute physically active learning and classroom movement breaks on children's physical activity, cognition, academic performance and classroom behaviour: understanding critical design features. *BMJ Open Sport Exerc Med*. 2018;4:e000341.
15. Haverkamp BF, Wiersma R, Vertessen K, van Ewijk H, Oosterlaan J, Hartman E. Effects of physical activity interventions on cognitive outcomes and academic performance in adolescents and young adults: a meta-analysis. *J Sports Sci*. 2020;38:2637-2660.
16. Ortega FB, Mora-Gonzalez J, Cadenas-Sanchez C, et al. Effects of an exercise program on brain health outcomes for children with overweight or obesity: the ActiveBrains randomized clinical trial. *JAMA Netw Open*. 2022;5:E2227893.
17. Ludyga S, Gerber M, Pühse U, Looser VN, Kamijo K. Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. *Nat Hum Behav*. 2020;4:603-612.
18. Webster CA, Russ L, Vazou S, Goh TL, Erwin H. Integrating movement in academic classrooms: understanding, applying and advancing the knowledge base. *Obes Rev*. 2015;16:691-701.
19. Abraham C, Michie S. A taxonomy of behavior change techniques used in interventions. *Health Psychol*. 2008;27:379-387.
20. Samdal GB, Eide GE, Barth T, Williams G, Meland E. Effective behaviour change techniques for physical activity and healthy eating in overweight and obese adults; systematic review and meta-regression analyses. *Int J Behav Nutr Phys Act*. 2017;14:42.
21. McDermott MS, Oliver M, Iverson D, Sharma R. Effective techniques for changing physical activity and healthy eating intentions and behaviour: a systematic review and meta-analysis. *Br J Health Psychol*. 2016;21:827-841.
22. Anselma M, Chinapaw MJM, Kornet-van der Aa DA, Altenburg TM. Effectiveness and promising behavior change techniques of interventions targeting energy balance related behaviors in children from lower socioeconomic environments: a systematic review. *PloS One*. 2020;15:e0237969.
23. Page MJ, Moher D, Bossuyt PM, et al. PRISMA 2020 explanation and elaboration: updated guidance and exemplars for reporting systematic reviews. *BMJ*. 2021;372:n160.
24. Ardern CL, Büttner F, Andrade R, et al. Implementing the 27 PRISMA 2020 Statement items for systematic reviews in the sport and exercise medicine, musculoskeletal rehabilitation and sports science fields: the PERSiST (implementing Prisma in exercise, rehabilitation, sport medicine and sports science) guidance. *Br J Sports Med*. 2022;56:175-195.
25. Altman DG, Bland JM. Standard deviations and standard errors. *BMJ*. 2005;331:903.
26. Maher CG, Sherrington C, Herbert RD, Moseley AM, Elkins M. Reliability of the PEDro scale for rating quality of randomized controlled trials. *Phys Ther*. 2003;83:713-721.
27. JPT H, Thomas J, Chandler J, Cumpston M, Page M, Welch V. Cochrane handbook for systematic reviews of interventions version 6.3. *Cochrane*. 2022; 2022.
28. JPT H, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. *BMJ*. 2003;327:557-560.
29. Furuya-Kanamori L, Barendregt JJ, Doi SAR. A new improved graphical and quantitative method for detecting bias in meta-analysis. *Int J Evid Based Healthc*. 2018;16:195-203.
30. Goodman SN. A comment on replication, P-values and evidence. *Stat Med*. 1992;11:875-879.
31. White IR. Multivariate random-effects meta-regression: updates to Mvmeta. *Stata J Promot Commun Stat Stata*. 2011;11:255-270.
32. Peng P, Lin X, Ünal ZE, et al. Examining the mutual relations between language and mathematics: a meta-analysis. *Psychol Bull*. 2020;146:595-634.
33. Mavilidi MF, Ouwehand K, Riley N, Chandler P, Paas F. Effects of an acute physical activity break on test anxiety and math test performance. *Int J Environ Res Public Health*. 2020;17.
34. Phillips D, Hannon JC, Castelli DM. Effects of vigorous intensity physical activity on mathematics test performance. *J Teach Phys Educ*. 2015;34:346-362.
35. Broad AA, Bornath DPD, Grisebach D, et al. Classroom activity breaks improve on-task behavior and physical activity levels regardless of time of day. *Res Q Exerc Sport*. 2021;00:1-13.
36. Duncan M, Johnson A. The effect of differing intensities of acute cycling on preadolescent academic achievement. *Eur J Sport Sci*. 2014;14:279-286.
37. Fiorilli G, Buonsenso A, Di Martino G, et al. Impact of active breaks in the classroom on mathematical performance and attention in elementary school children. *Healthc*. 2021;9:9.

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

38. Grieco LA, Jowers EM, Errisuriz VL, Bartholomew JB. Physically active vs. sedentary academic lessons: a dose response study for elementary student time on task. *Prev Med (Baltim)*. 2016;89:98-103.
39. Harveson AT, Hannon JC, Brusseau TA, et al. Acute exercise and academic achievement in middle school students. *Int J Environ Res Public Health*. 2019;16:1-7.
40. Hillman CH, Pontifex MB, Raine LB, Castelli DM, Hall EE, Kramer AF. The effect of acute treadmill walking on cognitive control and academic achievement in preadolescent children. *Neuroscience*. 2009;159:1044-1054.
41. Howie EK, Schatz J, Pate RR. Acute effects of classroom exercise breaks on executive function and math performance: a dose–response study. *Res Q Exerc Sport*. 2015;86:217-224.
42. Kawabata M, Lee K, Choo HC, Burns SF. Breakfast and exercise improve academic and cognitive performance in adolescents. *Nutrients*. 2021;13.
43. Pontifex MB, Saliba BJ, Raine LB, Picchietti DL, Hillman CH. Exercise improves behavioral, neurocognitive, and scholastic performance in children with attention-deficit/hyperactivity disorder. *J Pediatr*. 2013;162:543-551.
44. Mavilidi MF, Drew R, Morgan PJ, Lubans DR, Schmidt M, Riley N. Effects of different types of classroom physical activity breaks on children's on-task behaviour, academic achievement and cognition. *Acta Paediatr*. 2020;109:158-165.
45. Mavilidi MF, Ruiter M, Schmidt M, et al. A narrative review of school-based physical activity for enhancing cognition and learning: the importance of relevancy and integration. *Front Psychol*. 2018;9:9.
46. Skulmowski A, Rey GD. Embodied learning: introducing a taxonomy based on bodily engagement and task integration. *Cogn Res Princ Implic*. 2018;3:6.
47. Paas F, Sweller J. An evolutionary upgrade of cognitive load theory: using the human motor system and collaboration to support the learning of complex cognitive tasks. *Educ Psychol Rev*. 2012;24:27-45.
48. Campbell AL, Lassiter JW. Teacher perceptions of facilitators and barriers to implementing classroom physical activity breaks. *J Educ Res*. 2020;113:108-119.
49. Cassar S, Salmon J, Timperio A, et al. Adoption, implementation and sustainability of school-based physical activity and sedentary behaviour interventions in real-world settings: a systematic review. *Int J Behav Nutr Phys Act*. 2019;16:120.
50. Daly-Smith A, Quarmby T, Archbold VSJ, et al. Implementing physically active learning: future directions for research, policy, and practice. *J Sport Heal Sci*. 2020;9:41-49.
51. Chang YK, Liu S, Yu HH, Lee YH. Effect of acute exercise on executive function in children with attention deficit hyperactivity disorder. *Arch Clin Neuropsychol*. 2012;27:225-237.
52. McMorris T. The acute exercise-cognition interaction: from the catecholamines hypothesis to an interoception model. *Int J Psychophysiol*. 2021;170:75-88.
53. McMorris T, Hale BJ. Differential effects of differing intensities of acute exercise on speed and accuracy of cognition: a meta-analytical investigation. *Brain Cogn*. 2012;80:338-351.
54. Cantelon JA, Giles GE. A review of cognitive changes during acute aerobic exercise. *Front Psychol*. 2021;12:12.
55. Mavilidi MF, Mason C, Leahy AA, et al. Effect of a time-efficient physical activity intervention on senior school Students' on-task behaviour and subjective vitality: the 'burn 2 learn' cluster randomized controlled trial. *Educ Psychol Rev*. 2021;33:299-323.
56. Sibbick E, Boat R, Sarkar M, Groom M, Cooper SB. Acute effects of physical activity on cognitive function in children and adolescents with attention-deficit/hyperactivity disorder: a systematic review and meta-analysis. *Ment Health Phys Act*. 2022;23:100469.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Muntaner-Mas A, Morales JS, Martínez-de-Quel Ó, Lubans DR, García-Hermoso A. Acute effect of physical activity on academic outcomes in school-aged youth: A systematic review and multivariate meta-analysis. *Scand J Med Sci Sports*. 2023;00:1-14. doi:10.1111/sms.14479

16000838, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/sms.14479 by Universidad De Granada, Wiley Online Library on [30/10/2023]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License