Effects of physical education interventions on cognition and academic performance outcomes in children and adolescents: a systematic review and meta-analysis

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ABSTRACT

Objective To determine the effects of interventions aimed at optimising the quantity and quality of physical education (PE) on cognition and academic performance in children and adolescents.

Design A systematic review and meta-analysis.

Data sources Studies from electronic databases from inception to 3 January 2021 were identified.

Eligibility criteria for selecting studies Experimental studies that assessed the effect of quantity-based (ie, increasing the amount of curriculum time allocated to PE) or quality-based (ie, increasing students' participation in physical activity during PE) PE interventions, or both, on changes in cognition and/or academic performance in youth (aged 5–18 years) were included.

Results 19 trials comprising 8676 youth (46.5% girls) were included. Individual quality-based PE interventions increased cognition performance (Hedges' g=0.38, 95% CI 0.15 to 0.60; I^2=83.70%), mainly in primary education settings (g=0.48, 95% CI 0.07 to 0.89; I^2=90.43%). Academic performance, principally mathematics-related skills, was also increased by quality-based PE interventions (g=0.15, 95% CI 0.06 to 0.24; I^2=41.75%). Among these interventions, teaching strategies favoured similar results, but without heterogeneity in the results (g=0.12, 95% CI 0.05 to 0.18; I^2=0%). In contrast, quantity-based PE interventions had a very small and non-significant effect on academic performance (g=0.09, 95% CI −0.05 to 0.24; Q=11.65; I^2=48.48%). Finally, there were no differences between the three PE interventions (ie, quantity, quality, and combined PE interventions) in regard to academic performance.

Conclusion Improving the quality of PE classes may improve students' cognition and academic performance in children and adolescents. Importantly, allocating more time for PE does not seem to compromise this performance.

INTRODUCTION

The effects of physical activity on cognitive and academic performance in children and adolescents have been widely studied. Several reviews and meta-analyses on this topic have been published in recent years,[1–5] and have generally concluded that physical activity is positively associated with cognition and academic performance in children and adolescents. For example, Alvarez-Bueno *et al*[1] suggested that physical activity benefits several domains of cognition (eg, non-executive and executive functions) and metacognition in children and adolescents. The same authors demonstrated that physical activity improves classroom behaviour and benefits several aspects of academic performance in youth, especially mathematics-related skills.[2] In contrast, a review developed by an expert panel confirmed the positive association with mathematics-related skills, but found inconclusive evidence for other cognitive and overall academic performance outcomes.[6]

Schools are ideal settings for the promotion of healthy lifestyles in children and adolescents, and physical education (PE) is the primary vehicle to achieve these objectives.[7] As academic training of youth is, in large part, a task entrusted to the educational system, instructional time for core academic subjects (eg, mathematics and languages) is preserved and protected in the pursuit of academic achievement.[8] Unfortunately, this often happens at the expense of time spent in PE.[9] There is no evidence, however, to indicate that time allocated to PE has an adverse effect on academic performance and cognition[10]; in fact, quite the reverse may be true.[1 2 11]

There have been numerous studies designed to improve the quality and quantity of physical activity in school PE lessons.[7 12] Both approaches appear to be beneficial in terms of increasing the amount of physical activity students accumulate at school,[12] and improving students' fitness and movement skill proficiency.[7] For the purpose of this review, we differentiate between quantity-based (ie, those focused on increasing the amount of curriculum time allocated to PE) and quality-based (ie, those focused on increasing students' participation in physical activity during existing PE lessons) PE interventions. It is important to note that quality PE also provides opportunities for students to develop important cognitive, affective and psychomotor outcomes.[13] Despite the abundance of studies on this topic, to our knowledge, no systematic review or meta-analysis has quantitatively synthesised the effects of PE interventions on cognitive and academic outcomes.

Given the importance of students learning and acquiring enjoyment of learning, metacognition, and life skills later in life,[14] it seems relevant to determine the beneficial effects of quantity- and

quality-based PE interventions on student learning, and meta-analytic research is needed to assess which intervention strategies produce the strongest effects.[10] Accordingly, the aim of the present meta-analysis was to determine the effects of studies aimed at optimising PE in terms of quantity, quality, or both, on cognition and academic performance in children and adolescents.

METHODS

Protocol and registration

This research followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement Checklist[15] and was registered in the International Prospective Register of Systematic Reviews (PROSPERO, CRD42021228957).

Eligibility criteria and study selection

To be eligible for inclusion in the present review, studies needed to meet the following criteria (using PICOS criteria): (1) Participants: apparently healthy children and adolescents aged 5 to 18 years old; (2) Intervention characteristics included only studies that increased the proportion of curriculum time allocated to PE (ie, quantity-based PE interventions), enhanced the quality of the PE lesson (ie, enriched PE lessons, PE specialist-led) or combined interventions (ie, quantity- and quality-based PE interventions); (3) Comparison: control group that received the regular school curriculum; (4) Outcome: cognition outcomes (eg, executive function, memory, attention) and/or academic performance (eg, composite score, mathematics, and language-related skills); (5) Study design: randomised controlled trials (RCTs), quasi-experimental trials, and cluster RCTs (cRCTs).

Search strategy

We performed an electronic search of MEDLINE, EMBASE, Cochrane Central Register of Controlled Trials (CENTRAL), and Web of Science databases from inception to 3 January 2021. The search strategy was supplemented with manual searches of the existing literature. First, the search strategy combined the following relevant terms: 'physical education' OR 'PE' OR 'P.E.' AND 'academic performance' OR 'academic achievement' OR 'school performance' OR 'academic grades' OR 'academic behaviour' OR 'classroom behaviour' AND 'cognition' OR 'executive' OR 'executive function' OR 'cognitive control' OR 'intelligence' OR 'memory' OR 'attention'. The search strategy is described in detail in online supplemental emethod 1. Second, the reference lists of the included trials were checked to find potential studies that could also be used in the present study. Titles, abstracts and full texts were assessed for eligibility independently by two authors (AG-H and RR-V) for potential inclusion. If necessary, a third researcher (MI) was consulted.

Data collection process

For each study, data were extracted independently by two authors (AG-H and RR-V) and the following information was collected: (1) authors' names, year of publication and country of the study; (2) number of participants, sex and age in all groups (ie, intervention and control group); (3) characteristics of PE interventions regarding type, frequency, duration, intensity, and nature (ie, 'teaching strategies'—teachers learnt strategies to encourage physical activity by effective activity selection, class organisation and management, and instruction, or 'fitness infusion'—teachers supplemented students' participation in sport activities (eg, volleyball) with vigorous fitness activities (eg, running and jumping))[7 12]; (4) academic and cognition information about instruments used; and (5) results in all groups about the parameters of interest. When there was insufficient information, the authors of the included study were contacted.

Regarding cognition, studies were classified into two groups according to their measured outcomes: (1) core executive function: working memory, cognitive flexibility, selective attention-inhibition; and (2) metacognition: fluid intelligence and creativity. Creativity can be considered a cognitive outcome because it involves the acquisition of knowledge and skills, the transformation of knowledge into new forms, and the rendering of these forms into a shareable product.[16]

Risk of bias and quality of individual studies

The Physiotherapy Evidence Database (PEDro) was used to appraise each study critically.[17] This tool consists of 11 domains and was designed to measure the methodological quality of each trial.

Data synthesis and analysis

All analyses were conducted using Stata software (v16.1; StataCorp, College Station, TX, USA). We analysed effects using the DerSimonian-Laird random-effects inverse-variance model. Changes in outcomes were calculated by subtracting change differences between the intervention and control groups, using the pooled standard deviation (SD) of change in both groups. If change scores SD were not available, they were calculated from 95% confidence intervals (95% CI) for either change outcome or intervention effect differences as well as pre-SD and post-SD values.[18] The effects sizes were expressed as Hedges' g to correct for possible small sample sizes[19] and classified as small ($0 \leq g \leq 0.50$), moderate ($0.50 < g \leq 0.80$) and large (>0.80).[20] It is important to clarify the following aspects relating to our statistical analyses: (1) meta-analyses were only performed for outcomes that were included in five or more studies[21]; (2) when different cohorts,[22] interventions[23–25] or sexes[26 27] were included in studies, their data were analysed as independent samples; and (3) when two or more tests for measuring the same variable were included in a study,[24 28] we calculated the average Hedge's g using fixed effect models. In regards to academic performance, when a study included several outcomes (eg, mathematics, language, composite score), we used only the composite score, rather than the average effect size. Also, whenever possible, an analysis of variance (ANOVA)-like random effects model developed for meta-analytic research was used to compare effect size differences between PE interventions (ie, quantity, quality or combined PE interventions) and nature of quality-based PE interventions (ie, teaching strategies or fitness infusion).

Heterogeneity across studies was calculated using the inconsistency index (I^2), derived from the Cochran Q statistic[29] and using the tau-squared (τ^2) test. Percentage of variation across studies was estimated using I^2, considering I^2 values of 30%, 50% and 75% as low, moderate and high heterogeneity, respectively.[30] For its part, if τ^2 is above 1, it suggests substantial heterogeneity between centres.

Small-study effects and publication bias were examined using the Luis Furuya-Kanamori (LFK) index and the Doi plot, respectively. Both tests have been shown to be more robust that the traditional funnel plot and Egger's regression intercept test.[31] Values of –1, between –1 and –2, and >–2 are considered to represent no, minor, and major asymmetry, respectively.[31] The trim-and-fill computation was used to assess the effect of publication bias on the interpretation of results.[32]

Finally, whenever possible, a subgroup analysis was conducted according to the domains of cognition (ie, core executive function or metacognition), areas of academic performance (eg, mathematics-related skills and language-related skills), the nature of the quality-based interventions (ie, teaching strategies or fitness infusion), the design of the study (experimental (RCT) or quasi-experimental), and education level (primary (5–12 years old) or secondary (13–18 years) education). Finally, random-effects meta-regression analyses

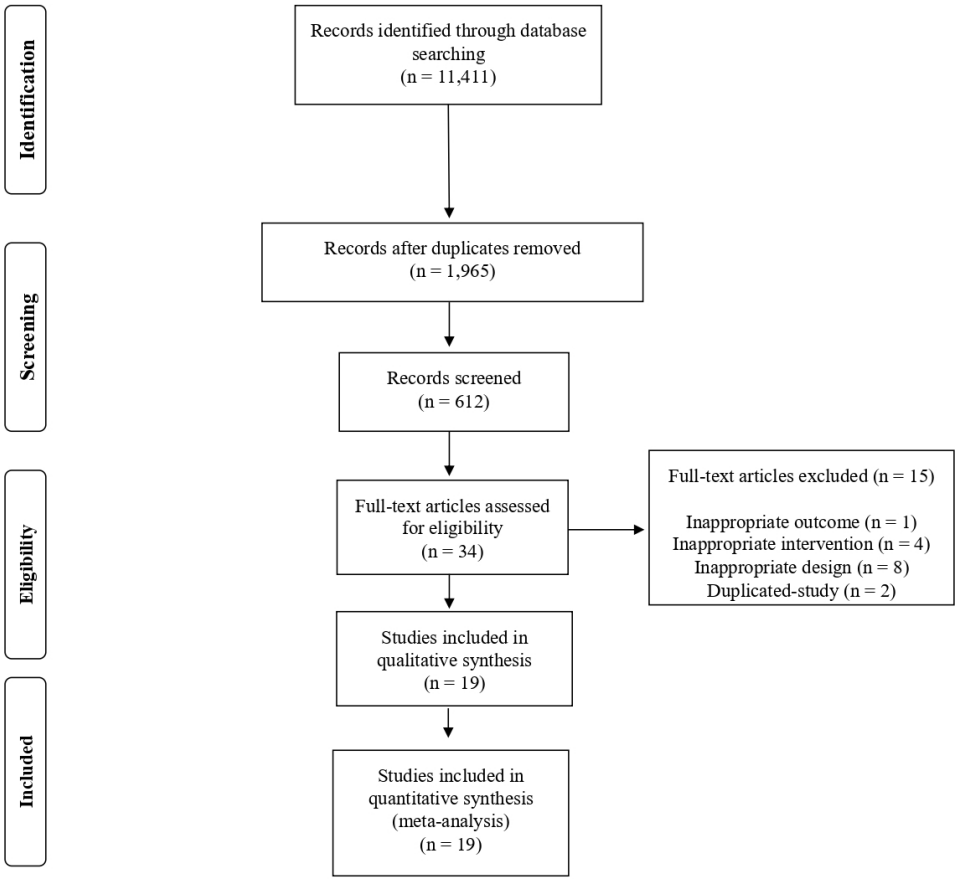

Figure 1 PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram.

were used to evaluate relationship between duration of intervention and effect size.

RESULTS

Study selection

A total of 19 studies were included in the present systematic review and meta-analysis, although two studies used several interventions[33 34]: six studies examined quantity-based PE,[26–28 33–35] 13 examined quality-based PE,[22–24 34 36–44] and four combined the two interventions (ie, combined quantity and quality-based PE).[25 33 34 45] Also, two different publications used the same dataset.[37 38] The reasons for exclusion and references are shown in online supplemental emethod 2. The PRISMA flow diagram is shown in figure 1.

Study characteristics

The study characteristics are summarised in table 1. The systematic review and meta-analysis included three cRCTs,[25 34 42] 12 RCTs,[22–24 33 35–37 39 41 43 44 46] and four quasi-experimental studies,[26–28 45] with a total of 8676 apparently healthy children and adolescents. All studies included boys and girls (53.5% and 46.5%, respectively).

Studies were conducted in 11 countries: Australia,[24 42] Brazil,[34] Canada,[36] Denmark,[45] Italy,[43 44] USA,[22 28 35 41] UK,[39 46] Spain,[33 37 38] Sweden,[26 27] Switzerland,[23] and The Netherlands.[25]

Intervention characteristics

Concerning interventions, studies aimed at increasing the amount of PE sessions per week (ie, quantity-based PE), by adding two,[35 45] three[27 47] or four[26 28] additional PE classes, with an average of 106.7 min per week of differences between PE intervention and control groups. Regarding the quality-based PE studies, seven studies used 'teaching strategies' (eg, enriched PE lessons, PE specialist-led) and four studies used 'fitness infusion' (eg, high-intensity activities, sports, team games).[23 24 37 41] Interventions that used combined quantity- and quality-based PE added two additional PE sessions per week and included 'fitness infusion'[25 33] or 'teaching strategies'.[34 45] Duration of the interventions ranged from 8 weeks[24] to 9 years.[26 27]

Outcomes

Several studies included information concerning the impact of PE on scores for language-related skills (eg, spelling, language, vocabulary, writing and reading),[22 25 33 36 38] mathematics-related skills (eg, mathematics, numeracy and arithmetic)[22 25 33 34 36 38 42] and composite scores.[26 27 33 35 45] Regarding cognitive domains, several studies considered a range of individual tasks concerning core executive function (ie, working memory, cognitive flexibility, selective attention-inhibition)[23 24 33 38 41 43 44 46] and metacognition (ie, fluid intelligence and creativity).[28 37]

Risk of bias within studies

Studies met between three and seven criteria on the PEDro scale (online supplemental etable 1). Low scores corresponded to studies that failed to conceal allocation, or to blind subjects and professors (very difficult to do in school-based studies), or had researchers in charge of endpoint assessment.

Summary of evidence

Quantity-based PE interventions

Cognition. Only two studies analysed quantity-based PE interventions and cognition variables.[28 33]

Table 1 Summary of included studies

Author, year, country	Design	Sample, age (range or mean)	Intervention length	Intervention characteristics and duration per session	Outcomes (test)
Quantity-based physical education					
Coe *etal* 2006, USA[35]	RCT	214 (49% girls) 11.5 years old	24 weeks	IG: 2 sessions per week and 55 min per session CG: no physical education	Composite score (Terra Nova standardised test scores)
Cöster *et al* 2018, Sweden[26]	CT	304 (45% girls); 6–7 years old	9 years	IG: 5 sessions per week and 40 min per session CG: 1 session per week of 60 min	Composite score (grades from the Swedish National Agency for Education)
Ericsson and Karlsson 2014, Sweden[27]	CT	220 (46% girls); 7–9 years old	9 years	IG: 5 sessions per week of 45 min CG: 2 sessions per week of 45 min	Composite score (grades from the Swedish National Agency for Education)
Reed *et al* 2013, USA[28]	CT	470 (50% girls); 10.2 years old	1 year	IG: 5 sessions per week of 45 min CG: 1 session per week of 30–45 min	Fluid intelligence (the Standard Progressive Matrices)
Quality-based physical education					
Costigan *et al* 2016, Australia[24]	RCT	65 (30.8% girls); 14–16 years old	8 weeks	Fitness infusion; adolescents completed high-intensity interval training sessions primarily involving gross motor cardiorespiratory exercises (IG1) or cardiorespiratory and body weight resistance training exercises (IG2)	Executive function (the trail making test)
Dalziell *et al* 2019, UK[39]	RCT	143 (NR); 10–11 years old	16 weeks	Teaching strategies; Better Movers and Thinkers was designed as a novel approach to physical education that directly targets the development of physical competence, cognitive skills and personal qualities	Cognitive function (Cognitive Assessment System)
Fisher *et al* 2011, UK[46]	RCT	64 (55% girls); 5–6 years old	10 weeks	Teaching strategies; teachers received training in the experimental intervention physical education programme and were encouraged to make the sessions 'as physically active as possible', 'minimise instruction time' and 'minimise/avoid any time children were waiting to use equipment, or standing around; minimise object control tasks'	Cognitive function (Cognitive Assessment System); attention (Attention Network Test); working memory (Cambridge Neuropsychological Test Battery)
Lakes and Hoyt, 2004, USA[41]	RCT	193 (51.3% girls); NR	12 weeks	Fitness infusion; Leadership Education Through Athletic Development curriculum, a programme born out of the Moo Gong Ryu (Korean for 'guardian of peace style') martial arts system	Attention (Wechsler Intelligence Scale for Children, third edition)
Lubans *et al* 2018, Australia[42]	cRCT	1173 (44.5% girls); 12.9 years old	14–15 months	Teaching strategies; the Activity and Motivation in Physical Education (AMPED) intervention was designed to help teachers maximise opportunities for moderate-to-vigorous physical activity in physical education lessons; and to help teachers enhance their students' motivation toward physical education	Mathematics (National Assessment Program-Literacy and Numeracy)
Martínez-López *et al* 2018 (Spain) Ruiz-Ariza *et al* 2019 (Spain)[37 38]	RCT	184 (46.7% girls); 12–16 years old	12 weeks	Fitness infusion; adolescents performing 16 min of cooperative high-intensity interval training at the beginning of each physical education session	Language; mathematics (ad hoc test); attention and concentration (d2 test); creativity (CREA test)
Pesce *et al* 2016, Italy[43]	RCT	90 (36.7% girls); 14–15 years old	6 months	Teaching strategies; the life skills programme was integrated into a multisport approach to physical education including a variety of closed skill (eg, track and field) and open skill (eg, volleyball) sport activities.	Inhibition; working memory (Random Number Generation task)
Pesce *et al* 2016, Italy[44]	RCT	920 (48% girls); 5–10 years old	6 months	Teaching strategies; the enriched physical education was centred on deliberate play and cognitively challenging variability of practice, on motor coordination and cognitive processing	Inhibition; working memory (Random Number Generation task); attention (Cognitive Assessment System)
Sallis *et al* 1999, USA[22]	RCT	955 (49% girls); 9.5–9.6 years old	2 years	Teaching strategies; Sport, Play, Activity, and Recreation for Kids (SPARK) physical education intervention: physical education specialist-led: physical education teachers taught physical education and self-management while receiving ongoing professional development and supervision from investigators.	Language; mathematics; reading; composite score (Metropolitan Achievement Tests)

Continued

Table 1 Continued

Author, year, country	Design	Sample, age (range or mean)	Intervention length	Intervention characteristics and duration per session	Outcomes (test)
Schmidt *et al* 2015, Switzerland[23]	RCT	181 (55% girls); 10–12 years old	6 weeks	Fitness infusion; Children were assigned to either a physical education programme with a high level of physical exertion and high cognitive engagement (IG1: team games), or a physical education programme with high physical exertion but low cognitive engagement (IG2: aerobic exercise)	Cognitive flexibility (Flanker task); inhibition (Flanker task); working memory (non-spatial n-back task)
Telford *et al* 2012, Canada[36]	RCT	620 (NR); 7–8 years old	2 years	Teaching strategies; Lifestyle of Our Kids study: the specialist-taught intervention was conducted in 13 schools by 1 of 3 visiting physical education teaching specialists and involved 2 classes of 45 to 50 min per week for 75 of the 80 weeks of school over the 2 year period	Numeracy; writing; reading (government tests)
Combined quality- and quantity-based physical education					
Ardoy *et al* 2014, Spain[33]	RCT	67 (36% girls); 12–14 years old	16 weeks	IG1: 4 sessions per week of 55 min IG2: 4 sessions per week of 55 min + fitness infusion: high intensity activities (ie, heart rate above 120 bpm) CG: 2 sessions per week of 55 min	Cognitive function (Factorial Intelligence Test) Mathematics; language; composite score (grades from the official school's records at two moments)
Bugge *et al* 2018, Denmark[45]	CT	696 (41% girls); 6–7 years old	3 years	IG: 4 sessions per week and 45 min per session + teaching strategies; all physical education teachers at intervention schools were trained in specific age-related training principles, developed by Team Denmark, the Danish Elite Sport Foundation CG: 2 sessions per week and 45 min per session	Composite score (Danish National Test System)
De Brujin *et al* 2020, The Netherlands[25]	cRCT	819 (50.6% girls); 9–10 years old	14 weeks	IG1: 4 sessions per week of 30 min + fitness infusion: aerobic activities and moderate-to-vigorous intensity IG2: 4 sessions per week of 30 min + fitness infusion: cognitively engaging intervention focused on challenging cognition and motor skills via games CG: 2 sessions per week	Reading; mathematics; spelling (standardised test battery)
Lima *et al* 2020, Brazil[34]	cRCT	1296 (55.8% girls); 14.9 years old	20 weeks	IG1: 4 sessions per week of 45 min IG2: Teaching strategies; workshop with the physical education teachers. Each workshop was structured to present pedagogical and health-related topics to the physical education teachers IG3: 4 sessions per week of 45 min + workshops CG: 2 sessions per week of 45 min	Mathematics (standardised test battery)

IG: intervention group; bpm, beats/min; CG, control group; cRCT, cluster-randomised controlled trial; CT, controlled trial; NR, not reported; RCT, randomised controlled trial.;

Academic performance. Quantity-based PE interventions had a very small and non-significant effect on academic performance (g=0.09, 95%CI −0.05 to 0.24, p=0.202; Q=11.65; I^2=48.48%; τ^2=0.02) (figure 2). Subgroup analyses were not possible due to the limited number of studies included. It is important to consider that all studies included except one[33] were quasi-experimental design.

In addition, meta-regression analysis found that duration of the quantity-based PE interventions were not associated with changes in academic performance (β=0.001; p=0.907).

The Doi plot and the LFK index of 0.93 showed no asymmetry, verifying the absence of publication bias (online supplemental efigure 1). Additionally, the Duval and Tweedie trim-and-fill method identified no potentially missing study.

Sensitivity analyses suggested that the pooled effect size estimation was only modified when removing Ericsson and Karlsson[27] (g=0.13, 95% CI 0.01 to 0.25).

Quality-based PE interventions

Cognition. Quality-based PE interventions increased cognition (g=0.38, 95%CI 0.15 to 0.60, p<0.001; Q=55.21; I^2=83.70%; τ^2=0.11) (figure 3), specifically core executive function. Regarding the nature of the intervention, fitness infusion favoured slightly lower increases in cognition (g=0.23, 95%CI 0.12 to 0.35, p=0.032; Q=6.67; I^2=25.01%; τ^2=0.01) (online supplemental efigure 2). Concerning the design of the studies, all were RCTs or cRCTs. For educational level, analyses for primary education found slightly higher effects to the overall findings (g=0.48, 95%CI 0.07 to 0.89, p<0.001; Q=52.27; I^2=90.43%; τ^2=0.22) (online supplemental efigure 3).

Meta-regression analysis found that duration of the quality-based PE interventions was not associated with changes in cognition (β=−0.002; p=0.272).

The LFK index for the Doi plots showed a minor asymmetry, indicating a minor risk of publication bias (LKF index=1.63) (online supplemental efigure 4). Additionally, the Duval and Tweedie trim-and-fill method identified no potentially missing study.

Finally, the sensitivity analyses indicated no modifications in the results after removing one study at a time.

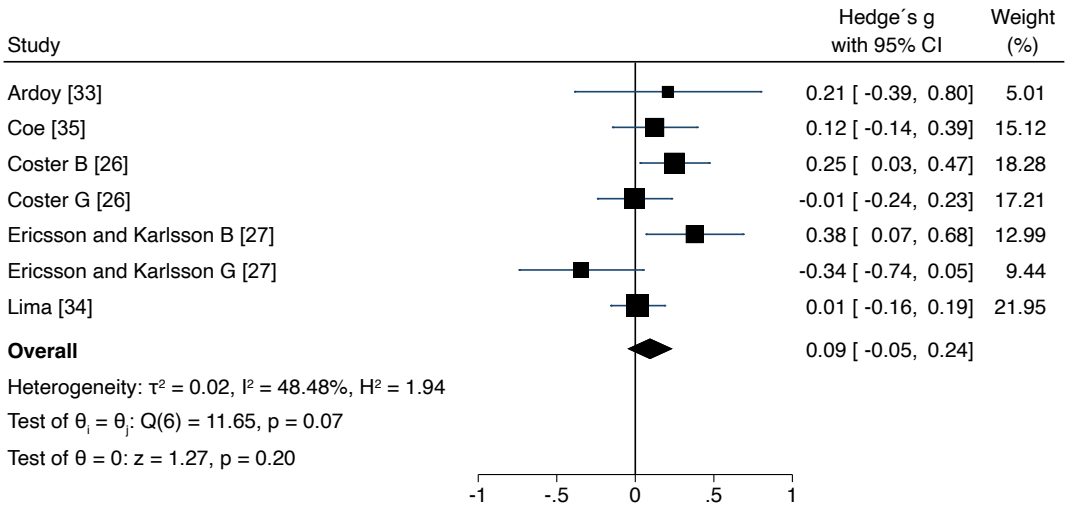

Figure 2 Forest plot showing the effects sizes (Hedge's g) of quantity-based physical education interventions on academic performance outcomes for each study. B, boys; G, girls.

Academic performance. The interventions favoured an increase in overall academic performance over the controls (g=0.15, 95% CI 0.06 to 0.24, p=0.001; Q=8.58; I^2=41.75%; τ^2=0.005) (figure 4), mainly mathematics-related skills (g=0.15, 95% CI 0.05 to 0.24, p=0.002; Q=7.15; I^2=30.02%; τ^2=0.005) (online supplemental efigure 5). Regarding the nature of the interventions, teaching strategies favoured similar increases in academic performance, but without heterogeneity (g=0.12, 95% CI 0.05 to 0.18, p<0.001; Q=3.18; I^2=0%; τ^2=0) (online supplemental efigure 6). Concerning the design of the studies, all were RCTs or cRCTs.

Meta-regression analysis found that duration of the quality-based PE interventions was not associated with changes in academic performance (β=−0.001; p=0.192).

There was minor asymmetry in the Doi plot (LKF index =1.34) (online supplemental efigure 7). Additionally, the Duval and Tweedie trim-and-fill method suggested that one study needed to be imputed, providing a lower but still significant effect size, based on a more symmetrical funnel plot (g=0.11, 95% CI 0.01 to 0.22).

Results of sensitivity analyses revealed no substantial modifications in the results for academic performance after removing one study at a time.

Combined quantity- and quality-based PE interventions

Cognition. Only one study analysed both interventions and cognition variables.[33]

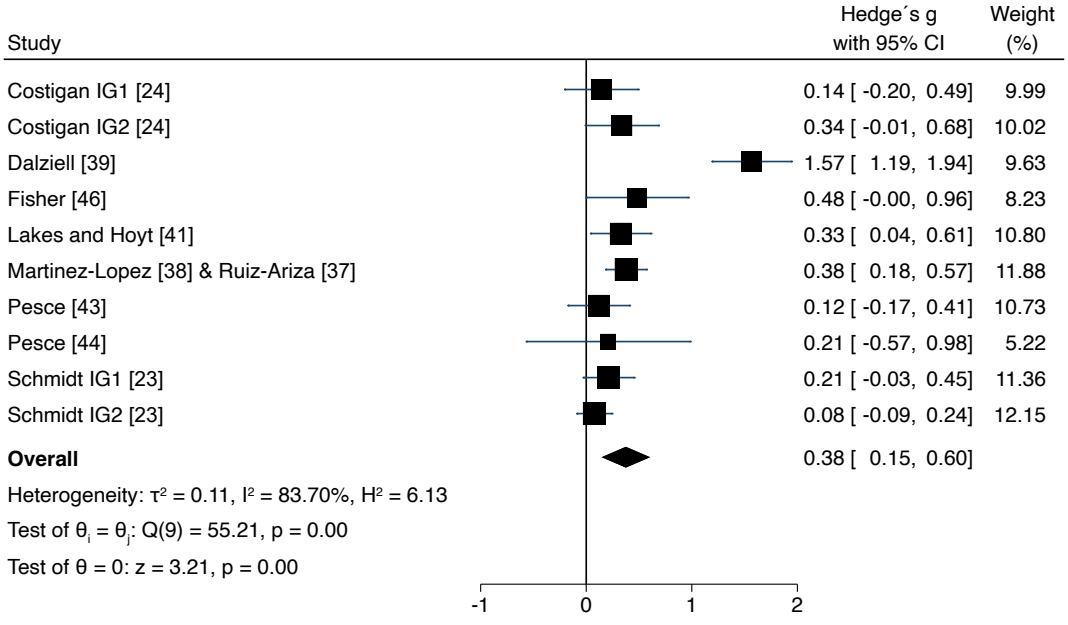

Figure 3 Forest plot showing the effects sizes (Hedge's g) of quality-based physical education interventions on cognition performance outcomes for each study. IG, intervention group.

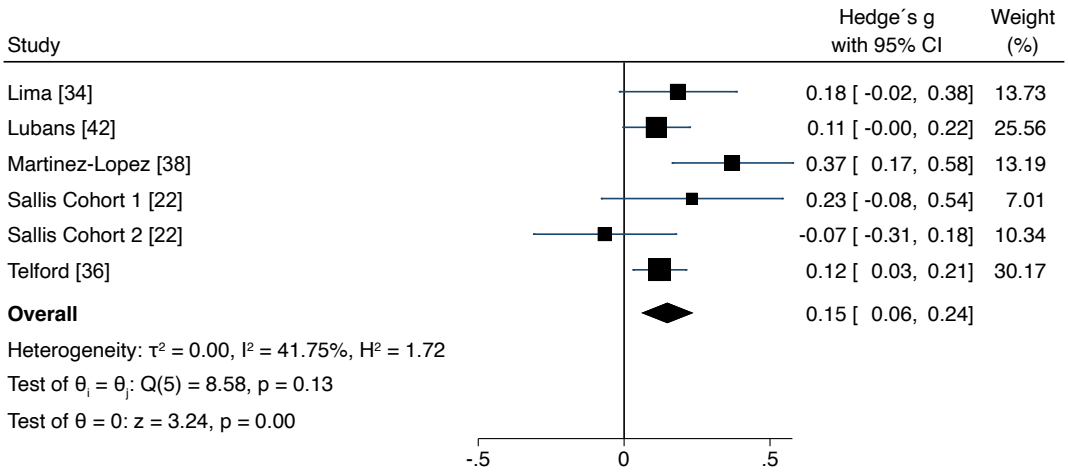

Figure 4 Forest plot showing the effects sizes (Hedge's g) of quality-based physical education interventions on academic performance outcomes for each study.

Academic performance. Combined quantity- and quality-based PE interventions had a small and non-significant effect on academic performance (g=0.15, 95% CI −0.03 to 0.32, p=0.100; Q=27.23; I^2=85.31%; τ^2=0.03) (figure 5) and by domain in mathematics-related skills (g=0.01, 95% CI −0.09 to 0.11, p=0.807; Q=6.32; I^2=36.69%; τ^2=0) (online supplemental efigure 8). Subgroup analyses were not possible due to the limited number of studies included.

Meta-regression analysis found that duration of the combined quantity- and quality-based PE interventions was not associated with changes in academic performance (β=−0.002; p=0.446)

Clear evidence of publication bias was found (LFK index=3.65) (online supplemental efigure 9). Additionally, the Duval and Tweedie trim-and-fill method identified no potentially missing study.

Results of sensitivity analyses revealed no substantial modifications in the results for academic performance after removing one study at a time.

Differences between PE interventions

There were no differences between PE interventions in academic performance (quantity- vs quality-based PE, p=0.530; quantity-based PE vs combined quantity- and quality-based PE, p=0.652; quality-based PE vs combined quantity- and quality-based PE, p=0.980) (online supplemental efigure 10).

DISCUSSION

To our knowledge, this is the first meta-analysis focused on the effects of interventions aimed at optimising PE in terms of quantity, quality, or both, on cognition and academic performance in children and adolescents. The main findings of this study are the following: (1) quality-based PE interventions increase cognition, mainly in primary education settings; and (2) quality-based PE interventions also favour an increase in academic performance, particularly mathematics-related skills and through teaching strategies interventions (ie, the results seem to be more homogeneous between trials). Regarding quantity-based (most quasi-experimental studies) and combined PE interventions (ie, quantity- and quality-based PE interventions), there are few studies and therefore our findings should be interpreted with caution. However, since their results are generally positive, there is a need and opportunity to evaluate the effects of interventions to increase the proportion of curriculum time allocated to PE and/or improving the quality of the PE classes in high-quality cluster RCTs.

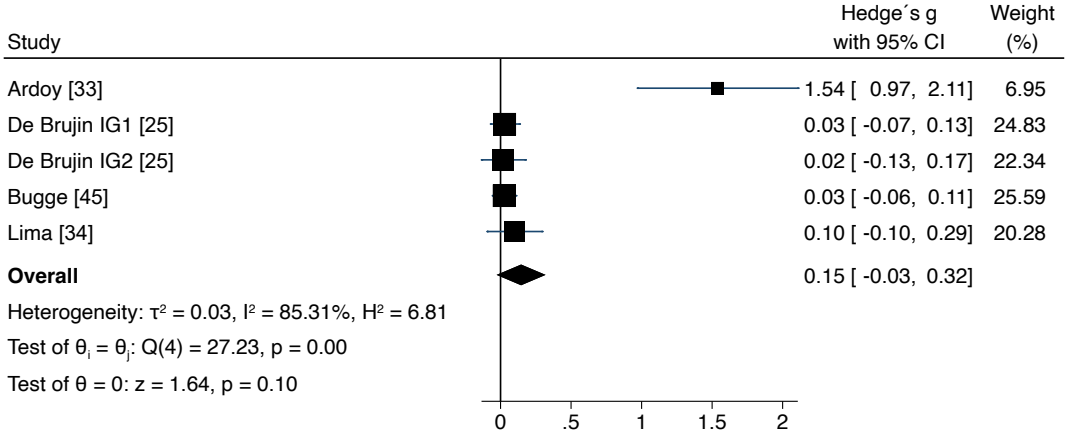

Figure 5 Forest plot showing the effects sizes (Hedge's g) of combined quantity- and quality-based physical education interventions on academic performance outcomes for each study. IG, intervention group.

In the last few years, developmental evidence has been accumulating regarding the beneficial effects of physical activity interventions on young people's cognition. Previous studies have suggested that physical activity may enhance cognition[1 3 4] by modifying white matter integrity and activating key regions of the brain responsible for cognitive processes.[48] However, it seems that not all exercise interventions produce similar results.[6] Alvarez-Bueno *et al*[1] found that curricular physical activity programmes seem to be the most effective intervention for promoting the development of a broad range of cognitive and metacognitive functions and skills. Consistent with the literature, our findings suggest that quality-based PE interventions can increase students' cognition, primarily core executive functions and in primary education settings.

Subgroup analysis revealed that fitness infusion interventions seem to produce slightly smaller improvements in cognition compared with overall results. Unfortunately, the limited number of studies do not allow us to analyse the effect of teaching strategies alone on cognition (n=4). In this regard, one RCT included in our review observed larger improvements in executive functions following the Better Movers and Thinkers programme, a novel approach to PE that directly targets the development of physical competence, cognitive skills and personal qualities.[39] Similarly, Pesce *et al*[44] compared traditional PE to enriched PE, centred on deliberate play and cognitively challenging variability of practice, on motor coordination and cognitive processing in children aged 5–10 years. The enhanced PE group showed greater improvements in inhibition, but not in working memory or attention. These findings add to the emerging evidence that cognitively challenging physical activities (eg, dance, martial arts) produce larger and more sustainable improvements in executive functions than physical activity involving low cognitive demand.[11 49] According to Tomporowski and Pesce,[50] the allocation of mental resources required during skill acquisition, independently from or interactively with the level of physical energy expenditure, is essential for reaping the largest cognitive benefit.

School PE is a significant environment for health-enhancing physical activity participation among children and adolescents.[7] Participation in physical activity may enhance cognitive function and academic outcomes through a variety of direct and indirect neurobiological, psychological, and behavioural mechanisms.[51] Based on our results, allocating more time for PE does not seem to compromise academic performance. On the contrary, our findings suggest that enhancing the quality of PE can have small improvements in students' academic performance. Specifically, no differences are observed between PE interventions in improving academic performance. In this regard, subgroup analysis revealed that teaching strategies favoured similar increases than overall results in academic performance, but without heterogeneity. However, slightly large positive effects seem to be related to high-intensity exercise interventions[33 37 38] or with interventions that improve students' cardiorespiratory fitness.[22 52] Regarding cardiorespiratory fitness, recent experimental,[53] longitudinal[54] and review studies[55] have corroborated its important role in academic performance. Also, quality-based PE interventions reported changes mainly in mathematics-related skills, which is in line with two meta-analyses[2 5] that concluded that the largest effectiveness of physical activity was found for this skill. It is worth noting that participation in physical activity has a robust effect on students' on-task behaviour in the classroom[56]; however, no studies have tested whether increasing the quality or quantity of PE leads to improvements in on-task behaviour.

Limitations

The limitations of the study that could compromise the robustness of our findings are as follows: (1) cognitive and academic performance was measured across the trials using a wide variety of instruments that vary substantially in validity and reliability; (2) interventions were heterogeneous with regards to the number of PE lessons per week in the intervention and control groups, their duration, and the follow-up time (from 8 weeks to 9 years); (3) we found significant publication bias in quantity- and quality-based PE interventions for academic performance; and (4) we included quasi-experimental studies, which introduced some risk of bias, mainly in quantity-based PE interventions.

What is already known

- Physical education (PE) is a primary vehicle to promote healthy lifestyles in children and adolescents.
- Effective PE strategies include quantity-based (eg, number of lessons per week) and quality-based (eg, supplementing usual physical education with fitness infusion) interventions.
- The effect of quantity- and quality-based PE interventions on students' cognition and academic outcomes is not fully understood.

What are the new findings

- Improving the quality of PE can result in small increases in students' cognition, mainly in primary education, and academic performance, particularly mathematics-related skills.
- No differences were observed between the three PE interventions (quantity, quality, and combined PE interventions) in improving academic performance.

CONCLUSION

Given the small number of trials, the heterogeneity of results, and the moderate-to-high risk of bias, caution is warranted regarding the strength of the existing evidence base. Nevertheless, findings from our meta-analysis suggest that improving the quality of PE classes is a worthwhile investment in education that may lead to improvements in cognition and academic performance. Our results highlight the importance of having access to quality PE for children and adolescents, as recommended by the United Nations Educational, Scientific and Cultural Organization (UNESCO).[14] Accordingly, schools should place more emphasis on PE not only to improve students' health,[7] but also to raise their cognition and academic performance.

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Contributors AG-H and MI conceptualised and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript. RR-V designed the data collection instruments, collected data, carried out the initial analyses, and reviewed and revised the manuscript. DRL conceptualised and designed the study, coordinated and supervised data collection, 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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