Physically active lessons in schools: A systematic review and meta-analysis of effects on physical activity, educational, health and cognition outcomes

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Abstract

Objective: This review provides the first meta-analysis of the effects of physically active lessons on lesson-time and overall physical activity (PA), as well as health, cognition and educational outcomes.

Design: Systematic review and meta-analysis. Six meta-analyses pooled effects on lesson-time PA, overall PA, in-class educational and overall educational outcomes, cognition and health outcomes. Meta-analyses were conducted using the metafor package in R. Risk of bias was assessed using the Cochrane tool for risk of bias.

Data sources: PubMed, Embase, PsycINFO, ERIC and Web of Science, grey literature and reference lists were searched in December 2017 and April 2019.

Studies eligibility criteria: Physically active lessons compared to a control group in a randomised or non-randomised design, within single component interventions in general school populations.

Results: 42 studies (39 in preschool or elementary school settings, 27 randomised controlled trials) were eligible for inclusion in the systematic review and 37 of them were included across the six meta-analyses (n=12,663). Physically active lessons were found to produce large, significant increases in lesson-time PA (*d*=2.33; 95%CI 1.42, 3.25: *k*=16) and small, significant effects on overall PA (*d*= 0.32, 95%CI 0.18, 0.46: *k*=8). A large, significant effect was shown on lesson-time educational outcomes (*d*=0.81; 95%CI 0.47, 1.14: *k*=7) and a small, significant effect on overall educational outcomes (*d*=0.36, 95%CI [0.09, 0.63], *k*=25). No effects were seen on cognitive (k=3) or health outcomes (k=3). 25/42 studies had high risk of bias in at least 2 domains.

Conclusion: In elementary and preschool settings, when physically active lessons were added into the curriculum they had a positive impact on both physical activity and educational outcomes. These findings support policy initiatives encouraging the incorporation of physically active lessons into teaching in elementary and preschool settings.

Review pre-registration: CRD42017076933

Introduction

Globally around 50% of children[1] and 80% of adolescents[2] do not obtain the 60 minutes of moderate-to-vigorous physical activity (MVPA) per day recommended by the World Health Organisation.[3] Classroom time is consistently shown to be the greatest contributor of sedentary time in children,[4] with obligatory teacher-led lessons contributing around 7-8 hours of sedentary time per day.[5] Increasing awareness of the health,[6] cognitive[7] and mental health benefits[8 9] of physical activity has led governments to recommend at least 30 minutes of moderate-to-vigorous physical activity (MVPA) per school day.[3 10] Schools provide an ideal environment to increase physical activity, as they allow prolonged access to the majority of children.[11 12] However, time constraints and education priorities make it difficult for teachers and schools to integrate activity opportunities into the school routine.[13 14]

Physically active lessons (also known as physically active learning[15]) combine physical activity with academic content and have been explored as a potential method of increasing activity in schools without detriment to educational time.[16] Examples of physically active lessons include doing star-jumps whilst reciting times tables [17] or using movements to show whether an answer is true or false[18]. Embedded physical activity can be specifically relevant to the learning task at-hand, or task non-relevant but still occurring simultaneously in the taught session[19]. Such activities also can take place inside or outdoors. Physically active lessons are distinct from 'brain-' or 'active breaks' which allow bouts of in-class activity but usually without educational content.[20]

Previous systematic reviews have collated research evidence for physically active lessons through qualitative syntheses.[15 20 21] These have identified mostly positive results on physical activity, health and educational outcomes across a wide range of study designs. However, it was not possible to synthesise findings identified in previous reviews due to the relative small number of studies.[20] A recent review assessed classroom-based physical activity interventions in general including active

breaks and other approaches, with 13/39 studies comprising of physically active lesson interventions[22]. This found classroom-based interventions to have a significant, positive effect on improving time-on-task and academic achievement, but no effects on cognitive functions or physical activity[22]. However, that review did not include a meta-analysis of the effects of physically active lessons specifically. Other reviews have meta-analysed physically active lessons amongst other school-based interventions, such as to explore effects on student engagement [23] and academic performance[24].

This review extends previous attempts to synthesise research by meta-analysing the effects of physically active lessons compared to typical teaching. This review aimed to assess the effects and moderators of physically active lessons on physical activity, educational, health and cognition outcomes.

Methods

The review protocol was registered with PROSPERO (CRD42017076933[25]) and PRISMA guidelines for systematic review reporting[26] were followed.

Search strategy and information sources

In December 2017, a systematic search was conducted using PubMed, Embase, PsycINFO, ERIC and Web of Science electronic databases. Searches were re-run in April 2019. Search terms included: 1) physical activity, exercise or movement, 2) class, lesson or learning and 3) children, young or pupil, all combined with 'AND' (Figure 1). Grey literature from related organisations was also searched, such as the Education Endowment Foundation (UK), Play England (UK), Active Living Research (USA) & Active Academics (USA). We also manually searched the reference lists of review studies.

Figure 1. Search strategy used in PubMed

1. physical activity or exercis* or movement* (title and abstract)

2. class* or lesson* or learn* (title and abstract)

3. child* or young* or pupil* (title and abstract)

1 and 2 and 3

Inclusion and exclusion criteria

Physically active lessons were required to be carried out in schools, with studies requiring a control group (e.g randomised or non-randomised controlled trials) to evaluate the effects of physically active lessons. Authors of related conference proceeding titles or abstracts were contacted for full text reports. Searches were restricted to English language studies published from January 1997.

Physically active lessons as part of multicomponent interventions were excluded as it would have been difficult to isolate their independent effects. Studies conducted in labs, testing physical education, physical activity breaks without educational content, after-school or recess interventions were excluded. Studies with exclusively special populations (such as children with Special Educational Needs or obesity) were excluded. Studies exclusively reporting protocol, qualitative or process evaluation findings were excluded. Reviews were also excluded although reference lists were searched. Studies meeting all criteria were included regardless of sample size, to reflect the variation of study sizes conducted to-date.

Study selection and data extraction

Search results were imported into Covidence[27] and duplicates removed. Titles, abstracts and full texts were screened by EN, AD & TvS, with disagreements discussed between these authors. All data from included studies were extracted onto a standardised, pre-piloted Excel form between February

and April 2018 and in April 2019 after searches were re-run. Data extraction was informed by the Template for Intervention Description and Replication (TiDieR)[28] checklist. Behaviour Change Techniques (BCTs) or the 'active ingredients' intended to elicit change in teachers and pupils were coded in identified studies by two independent coders (EN & AD) using the BCT Taxonomy v1 (BCTTv1[29]), addressing the 'What' component of TiDieR. Data were extracted from study protocols where available.

Outcome measurement methods and instruments were extracted related to physical activity (e.g questionnaires, observations, accelerometry), education (e.g time-on-task (often also referred to as on-task behaviour), academic achievement), health (e.g Body Mass Index; BMI) and cognition (e.g fluid intelligence and executive function, not time-on-task) with results extracted across all reported time-points. Data was only extracted where reported for both active lesson and control groups e.g not extracted where activity assessed during active lessons only. Data was independently extracted by two reviewers (split between EN, AD and TvS) and discrepancies resolved through discussion.

Risk of Bias assessment

Two reviewers (split between EN, AD and TvS) independently assessed risk of bias using the Cochrane Collaboration tool for assessing risk of bias.[30] Assessment was performed for random sequence generation, allocation concealment, blinding of participants and personnel, blinding of outcome assessment, incomplete outcome data and selective reporting. We assessed risk of bias for each criterion as low, unclear or high risk.

Meta-Analysis

Meta-analyses were conducted where there were at least three studies reporting statistics of interest for the same outcome (i.e group Means, SD and N) after contacting authors, e.g. cognitive testing, health outcomes, time-on-task[22]. We contacted authors for any missing, required data. A

decision strategy was set to prevent the inclusion of multiple outcomes from a single study in any one meta-analysis (e.g. two lesson-time physical activity measures such as observed and accelerometer-assessed activity from the same study[22].) For physical activity outcomes, MVPA was prioritised over steps, light activity and sedentary behaviour due to its focus in global physical activity guidelines[3]. For education outcomes, standardised testing (such as national standardised tests or progress monitoring tools) was prioritised over unstandardized researcher-developed testing.[22] Mathematic outcomes were prioritised where studies reported multiple subject assessments, as math was the most commonly reported outcome.[22] Higher scores typically indicated better educational outcomes, so scores were reversed where lower scores reflected better academic-related outcomes. For health outcomes, BMI was prioritised as it was the most commonly reported health outcome in included studies, making it more viable to pool rather than more heterogeneous health outcomes. Additionally, BMI was prioritised as children's overweight and obesity has greater focus in international child health profiles than children's physical fitness[3 31].

Analysis Strategy

We used the metafor-package for R[32] to conduct the meta-analyses with the standardised mean difference Cohen's d with Hedge's *g* correction as the effect size measure. For the weighting of studies, the inverse variance was computed. We calculated effect sizes and study weights using post-intervention scores of control and intervention groups and where outcomes were measured at multiple time points, we chose the first time point after the intervention had ended as effect size input. For studies where only change scores were available, we directly requested the post-test scores from authors via email.

Six random-effects models were fitted to the data, as there was an expectation of heterogeneity between studies due to differences in study design, length and outcome measures. Where applicable, Q-tests were conducted to test the assumption of heterogeneity that underlies the choice for random-effects models. Overall effects were calculated based on Cohen's suggestion

of small/medium/large effect size estimates of 0.3, 0.5, and 0.8 respectively[33], with additional sensitivity analysis performed using the leave-one-out method. We used the trim-and-fill method[34] to investigate possible publication bias in the included comparisons.

Moderators

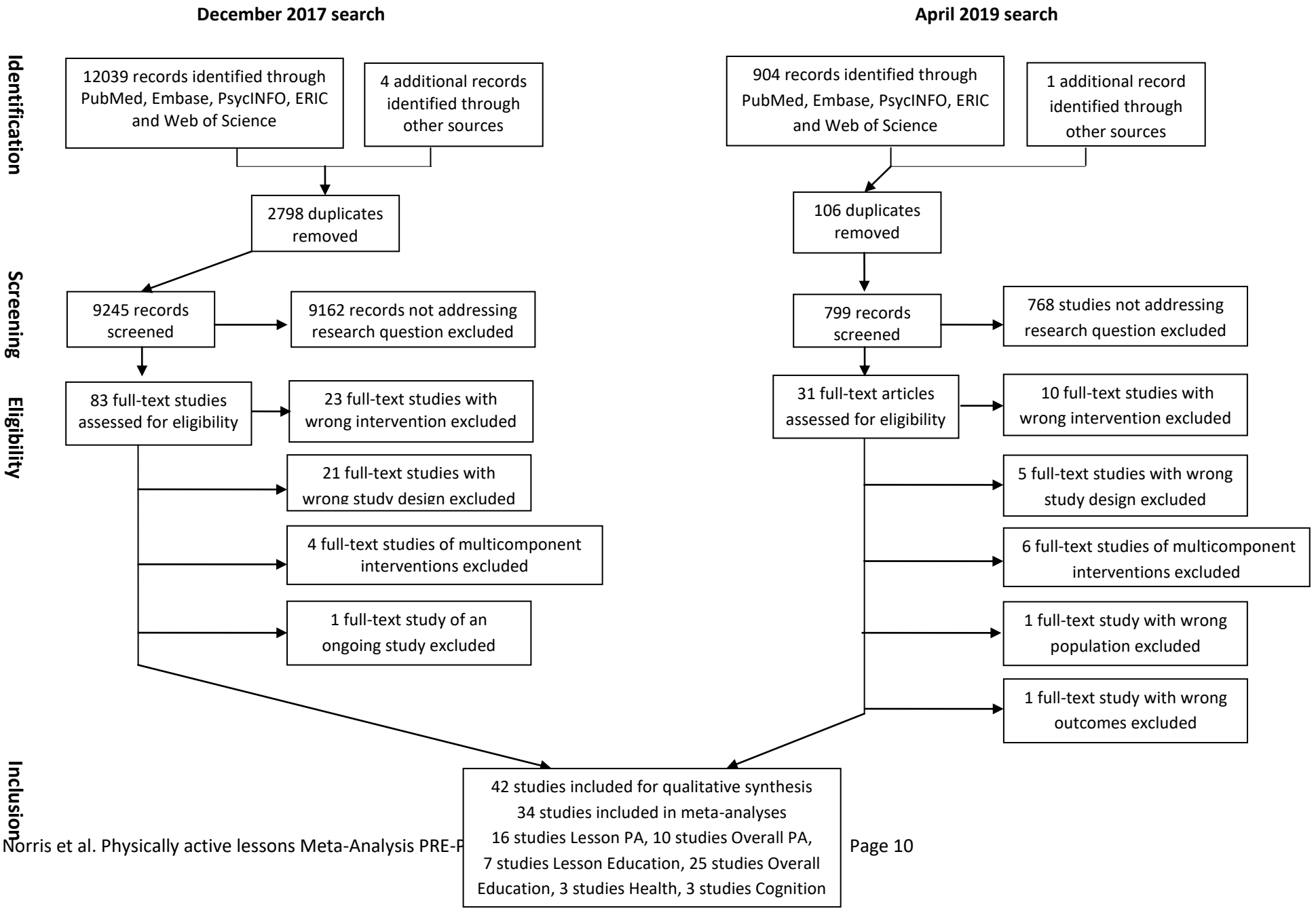
Moderator analyses assessed the robustness of the overall effect sizes. Seven dichotomous moderators were coded for: 1) risk of bias (high vs low - studies with at least one domain assessed as 'high risk of bias' were considered at a high risk of bias; excluding the blinding domain due to all studies assessed at high risk); 2) randomised controlled trial design (RCT vs not), 3) intervention length (> eight weeks vs < eight weeks - the median intervention length), 4) number of intervention sessions (one-off physically active lessons vs more than one), 5) school type (pre-school vs elementary school or higher), 6) source of intervention delivery (existing classroom teachers vs recruited personnel including teachers or research staff - to investigate the feasibility of physically active lesson interventions) and 7) physical activity measurement (subjective vs objective - self-report instruments or objectively captured PA via pedometer or accelerometer). The first six moderators were tested in all six meta-analyses, while physical activity measurement was only tested for in the overall physical activity and lesson-time physical activity meta-analyses. Differences in outcome variables by gender was not included as a moderator, as gender-stratified outcome data was only reported in five out of 42 studies.[35-39]

Results

Study selection

The final review included 42 studies (Figure 2), reporting the results of 38 trials, where four studies reported findings from the 'Fit en Vaardig op school' trial[40-43] and two studies reported findings from the 'A+PAAC' trial.[39 44] Supplementary File 1 provides an overview of each study.

Figure 2. Flow chart for identification of physically active lessons



Study and participant characteristics

Eighteen out of 42 studies delivered physically active lessons in the USA, seven in Australia, five in the UK, four in the Netherlands (all the same trial), two in Denmark and one in China, Croatia, Ireland, Israel, Portugal and Sweden respectively (Supplementary File 1). 27/42 studies were randomised controlled trials, four were non-randomised and 11 were quasi-experimental studies. 29/42 studies delivered interventions in an elementary school setting, nine in pre-schools, one in pre-school into elementary[45], one in elementary and middle schools[46] and two in high school[35 47] (Supplementary File 1). Intervention length ranged from one-off sessions[48-52] to three years[39 44 53 54]. Of studies providing physically active lessons on multiple occasions, total weekly intervention duration ranged from 10 minutes[55] to 180 minutes a day[56]. Only two studies were explicitly based on theory, namely the COM-B model of behaviour change[18 37]. One study presented a logic model of how it's physically active lesson intervention may impact student's sedentary behaviour and educational outcomes [47]. 33/42 studies reported interventions as delivered by existing classroom teachers (Table 1), with the remainder delivered by recruited personnel of teachers or researchers.

Sample sizes ranged from n=21[49] to n=2,493[53], with a total of n=12,663 across all included studies. Participant ages ranged from three[45 57-59] to 14 years old[35 47]. Gender proportions of participants ranged from 31.5%[57] to 59.4% boys[56]. 12 studies reported participants' ethnicity, with ethnic minorities representing between 7.1%[60] and 100%[57 58] of these samples. Seven studies reported free or reduced school meals status as a measure of socioeconomic status, with up to 94%[61] of participants receiving these.

Outcome assessments

Physical activity outcomes were assessed in 24 studies[17-19 36 37 39 44 47 48 51-55 57-66], with 21 assessing lesson-time activity[17-19 36 37 39 44 47 48 51-55 57-59 61-63 66] and 14 assessing overall physical activity[17 18 37 47 48 51 53 54 59 60 63-66] (Supplementary File 1). 15 studies assessed activity with accelerometers[17-19 37 47 48 51 53-55 59 62 63 66 67], eight with observations[18 39 44 54 57-59 61] (six of these using the System of Observing Fitness Instruction Time (SOFIT) momentary assessment tool[68], two with pedometers[64 65] and two with questionnaires[36 60]. Educational

outcomes were assessed in 36 studies[17-19 35 38 39 42-52 54-58 60-64 66 69-75], with 28 assessing overall education such as academic achievement[19 35 38 42-46 48 49 52 54-58 60-63 66 69-75] and eight assessing lesson-time educational outcomes of observed time-on-task[17 18 39 47 50 51 66 76]. Cognitive outcomes such as fluid intelligence were assessed in four studies[39 40 60 62 64 72]. Health outcomes were assessed in seven studies[36 40 41 44 54 63 75], with six assessing BMI[36 41 44 54 63 75] and five assessing cardiovascular fitness[40 41 44 63 75] (Supplementary File 1).

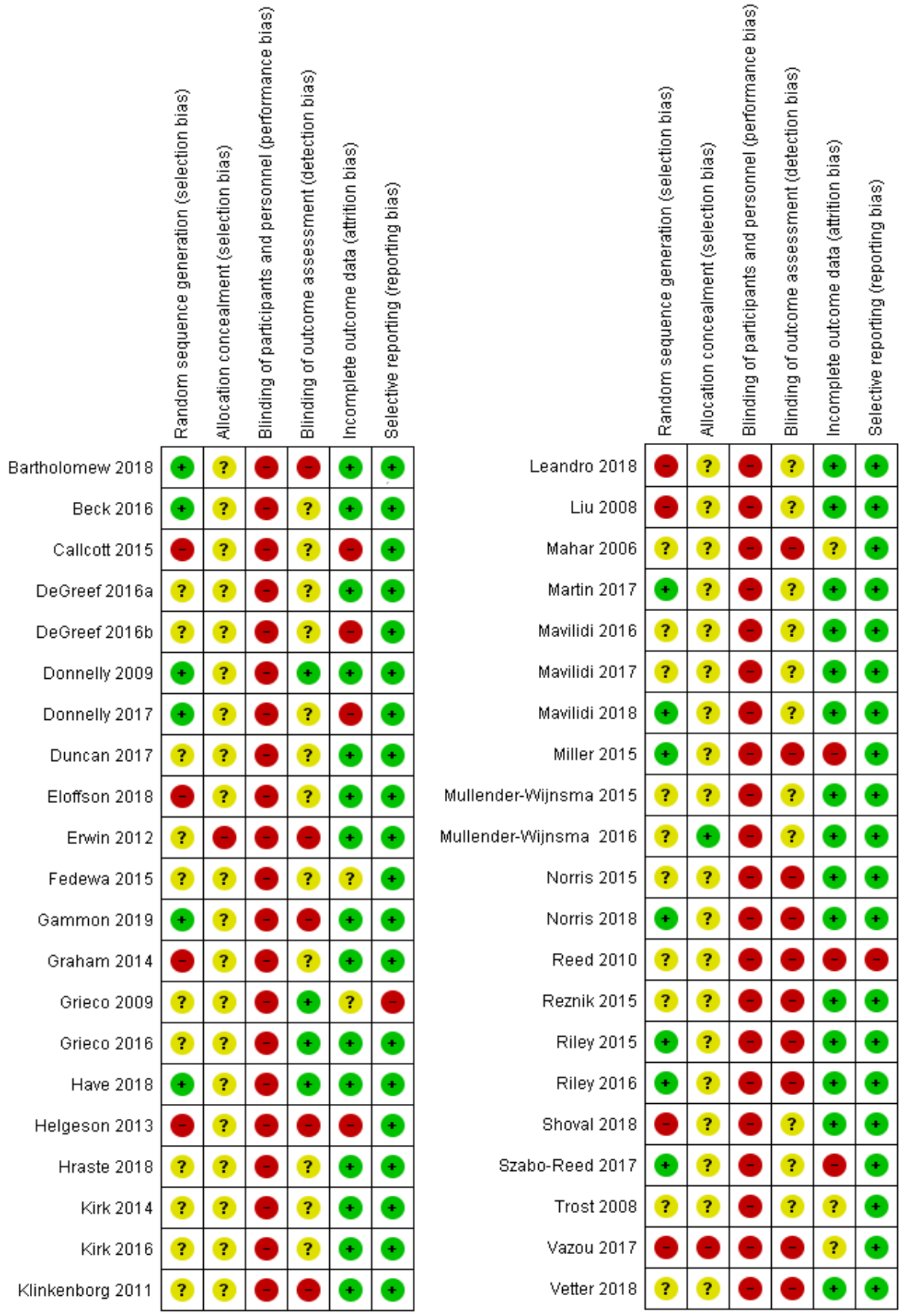
Behaviour Change Techniques (BCTs) used in interventions

Interventions contained an average of 3.9 BCTs, with a range between 0 and 12 (Supplementary File 2). The most frequently coded BCTs were Instruction on how to perform the behaviour (BCT 4.1: n=31/42), Adding objects to the environment (BCT 12.5: n=27/42), Self-monitoring of behaviour (BCT 2.3: n=16/42 and Feedback on behaviour (BCT 2.2: n=10/42). Objects added to the classroom were low-cost, such as a USB stick of pre-prepared physically active lessons[18] or an audio CD and CD player[65].

Risk of bias within studies

All 42 studies were assessed to be high risk on at least one domain, with 25/42 having additional high risk of bias in at least one other domain (Figure 3). Eight studies had high risk of random sequence generation selection bias, with the majority of studies reporting appropriate methods to their randomisation procedure (low risk of bias; n=13/42) or not describing these processes (unclear risk of bias; n=21/42). Allocation concealment selection bias was unclearly reported in 39/42 studies. All studies had high risk of performance bias, as blinding was not attempted in either the people delivering the intervention or in pupils receiving the intervention. 15 studies had high levels of detection bias, whereby outcome assessors were not blinded. Seven studies had high attrition bias, losing high proportions of their sample during the intervention, such as multiple schools dropping out for unclear reasons. 40/42 studies were judged at low risk of selective reporting bias. Overall, the risk of bias rating across all domains was relatively even between unclear (33.45%), low risk (33.1%) and high risk ratings (33.45%).

Figure 3. Risk of Bias assessment of identified physically active lesson studies.



Note: '+' denotes low risk of bias, '?' denotes unclear risk of bias and '-' denotes high risk of bias.

Intervention effects on outcomes

We conducted six meta-analyses: 1) lesson-time PA, 2) overall PA, 3) lesson-time educational outcomes, 4) overall educational outcomes, 5) health and 6) cognitive outcomes. Reasons for exclusion from meta-analyses were insufficient data from studies and authors not responding to requests for data (25 comparisons from 10 studies). See Figures 4-9 for forest plots of the six meta-analyses. See Table 1 for overall effects and subgroup effects of all six meta-analyses. An overview of outcomes in included studies and their moderator coding is in Supplementary File 3.

Table 1. Overall effects and subgroup effects of all meta-analyses.

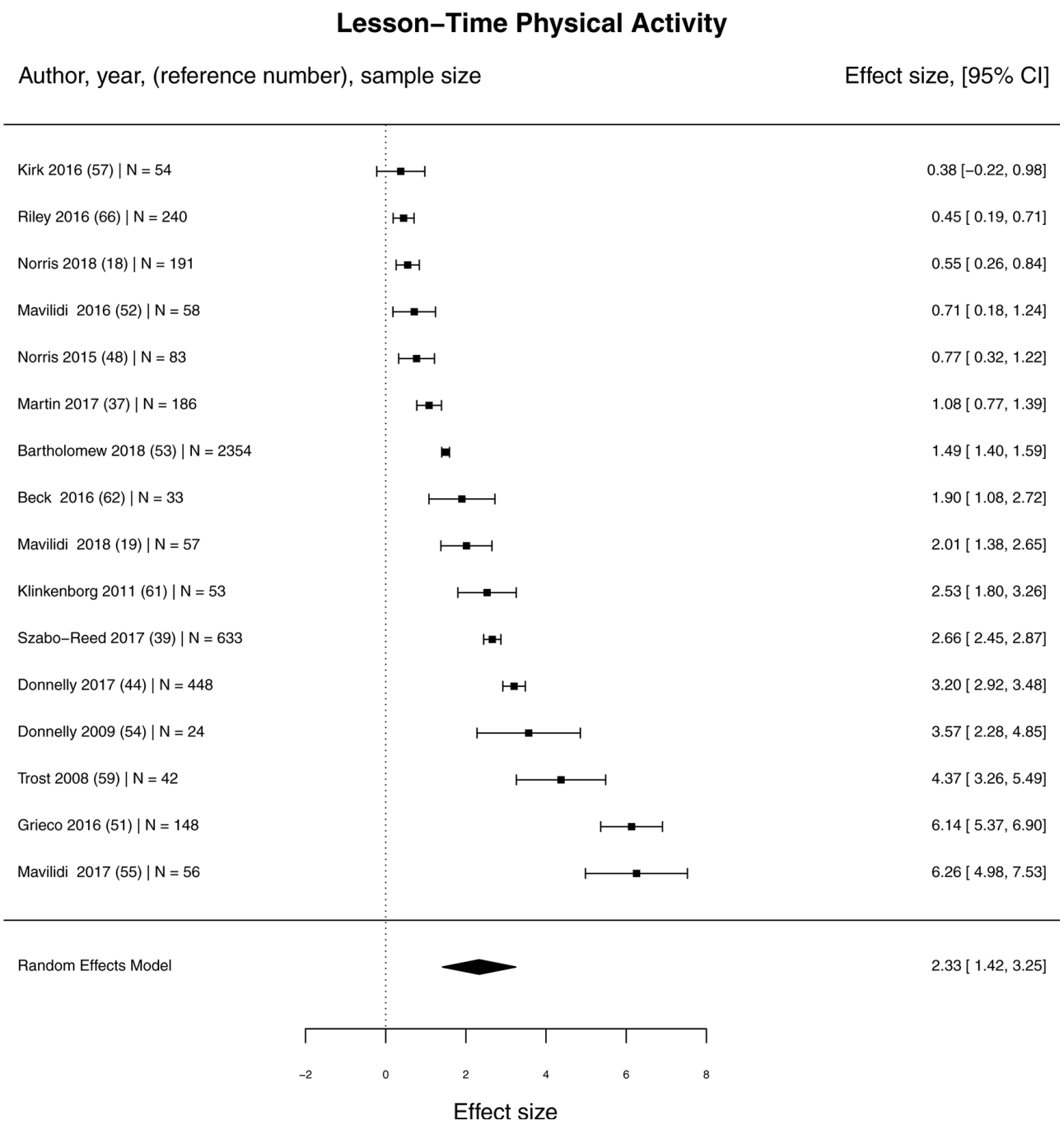
Meta-analysis	Moderator	Level	*k*	SMD	-95%CI	+95%CI	SE	Z-score	*p*
Lesson-time physical activity	Overall effect	-	16	2.33	1.42	3.25	0.47	5.00	<.0001
	Risk of bias	High risk of bias	7	1.66	0.32	3.00	0.68	2.43	0.015
		Low risk of bias	9	2.87	1.67	4.08	0.62	4.66	<.0001
	Study design	RCT	14	2.46	1.46	3.46	0.51	4.84	<.0001
		Non-RCT	2	1.45	-1.19	4.08	1.34	1.08	0.28
	Intervention length	Up to eight weeks	12	2.30	1.21	3.40	0.56	4.13	<.0001
		More than eight weeks	4	2.43	0.54	4.33	0.97	2.51	0.012
	Number of sessions	One-off session	3	2.51	0.33	4.69	1.11	2.26	0.024
		More than one session	13	2.29	1.24	3.35	0.54	4.27	<.0001
	School type	Pre-school	5	2.67	0.96	4.37	0.87	3.07	0.002
		Elementary and over	11	2.19	1.06	3.32	0.58	3.79	0.0002
	Physical activity measurement	Objective measurement	14	2.46	1.46	3.46	0.51	4.84	<.0001
		Subjective measurement	2	1.45	-1.19	4.08	1.34	1.08	0.28
	Intervention delivery	Existing classroom teacher	11	1.82	0.79	2.85	0.53	3.45	0.0006
		Recruited personnel	5	3.46	1.91	5.02	0.79	4.38	<.0001
Overall physical activity	Overall effect	-	8	0.32	0.18	0.46	0.07	4.56	<.0001
	Risk of bias	High risk of bias	6	0.28	0.12	0.44	0.08	3.44	0.0006
		Low risk of bias	2	0.46	0.16	0.77	0.16	2.97	0.003
	Study design	RCT	8	0.32	0.18	0.46	0.07	4.56	<.0001
		Non-RCT	0	-	-	-	-	-	-
	Intervention length	Up to eight weeks	7	0.30	0.15	0.44	0.08	3.89	0.0001
		More than eight weeks	1	0.51	0.07	0.95	0.22	2.29	0.0218
	Number of sessions	One-off session	1	0.03	-0.49	0.55	0.27	0.11	0.9093
		More than one session	7	0.34	0.20	0.48	0.07	4.79	<.0001
	School type	Pre-school	0	-	-	-	-	-	-
		Elementary and over	8	0.32	0.18	0.46	0.07	4.56	<.0001
	Physical activity measurement	Objective measurement	8	0.32	0.18	0.46	0.07	4.56	<.0001
		Subjective measurement	0	-	-	-	-	-	-
	Intervention delivery	Existing classroom teacher	7	0.32	0.17	0.48	0.08	4.05	<.0001
		Recruited personnel	1	0.25	-0.17	0.67	0.21	1.18	0.2378
Lesson-time educational outcomes	Overall effect	-	7	0.81	0.47	1.14	0.17	4.74	<.0001
	Risk of bias	High risk of bias	6	0.74	0.37	1.10	0.18	3.99	<.0001
		Low risk of bias	1	1.21	0.34	2.08	0.44	2.72	0.0065
	Study design	RCT	6	0.78	0.39	1.17	0.20	3.92	<.0001
		Non-RCT	1	0.93	0.01	1.85	0.47	1.98	0.0474
	Intervention length	Up to eight weeks	6	0.95	0.68	1.22	0.14	6.89	<.0001
		More than eight weeks	1	0.20	-0.35	0.75	0.28	0.73	0.4661
	Number of sessions	One-off session	2	1.07	0.46	1.67	0.31	3.45	0.0006
		More than one session	5	0.69	0.29	1.09	0.20	3.41	0.0007
	School type	Pre-school	0	-	-	-	-	-	-

		Elementary and over	7	0.81	0.47	1.14	0.17	4.74	<.0001
	Intervention delivery	Existing classroom teacher	6	0.74	0.37	1.10	0.18	3.99	<.0001
		Recruited personnel	1	1.21	0.34	2.08	0.44	2.72	0.0065
Overall educational outcomes	Overall effect	-	25	0.36	0.09	0.63	0.14	2.58	0.0098
	Risk of bias	High risk of bias	15	0.34	-0.03	0.70	0.19	1.80	0.0725
		Low risk of bias	10	0.40	-0.04	0.85	0.23	1.78	0.0755
	Study design	RCT	12	0.40	0.00	0.80	0.20	1.97	0.0492
		Non-RCT	13	0.33	-0.07	0.72	0.20	1.60	0.11
	Intervention length	Up to eight weeks	14	0.46	0.09	0.82	0.19	2.44	0.0146
		More than eight weeks	11	0.24	-0.16	0.64	0.20	1.18	0.24
	Number of sessions	One-off session	3	0.36	-0.48	1.21	0.43	0.84	0.40
		More than one session	22	0.36	0.06	0.66	0.15	2.37	0.0179
	School type	Pre-school	7	0.70	0.22	1.18	0.24	2.85	0.0044
		Elementary and over	18	0.22	-0.08	0.51	0.15	1.44	0.15
	Intervention delivery	Existing classroom teacher	19	0.24	-0.06	0.53	0.15	1.58	0.11
		Recruited personnel	6	0.73	0.20	1.26	0.27	2.72	0.0065
Health outcomes	Overall effect	-	3	-0.03	-0.11	0.05	0.04	-0.75	0.4519
	Risk of bias	High risk of bias	1	-0.04	-0.22	0.13	0.09	-0.45	0.6497
		Low risk of bias	2	-0.03	-0.12	0.06	0.05	-0.61	0.5406
	Study design	RCT	3	-0.03	-0.11	0.05	0.04	-0.75	0.4519
		Non-RCT	0	-	-	-	-	-	-
	Intervention length	Up to eight weeks	0	-	-	-	-	-	-
		More than eight weeks	3	-0.03	-0.11	0.05	0.04	-0.75	0.4519
	Number of sessions	One-off session	0	-	-	-	-	-	-
		More than one session	3	-0.03	-0.11	0.05	0.04	-0.75	0.4519
	School type	Pre-school	0	-	-	-	-	-	-
		Elementary and over	3	-0.03	-0.11	0.05	0.04	-0.75	0.4519
	Intervention delivery	Existing classroom teacher	2	-0.03	-0.12	0.06	0.04	-0.61	0.5409
		Recruited personnel	1	-0.05	-0.25	0.15	0.10	-0.48	0.631
Cognitive outcomes	Overall effect	-	3	0.01	-0.23	0.25	0.12	0.09	0.9294
	Risk of bias	High risk of bias	2	0.11	-0.22	0.44	0.17	0.65	0.5126
		Low risk of bias	1	-0.16	-0.60	0.29	0.23	-0.69	0.4901
	Study design	RCT	3	0.01	-0.23	0.25	0.12	0.09	0.9294
		Non-RCT	0	-	-	-	-	-	-
	Intervention length	Up to eight weeks	0	-	-	-	-	-	-
		More than eight weeks	3	0.01	-0.23	0.25	0.12	0.09	0.9294
	Number of sessions	One-off session	0	-	-	-	-	-	-
		More than one session	3	0.01	-0.23	0.25	0.12	0.09	0.9294
	School type	Pre-school	0	-	-	-	-	-	-
		Elementary and over	3	0.01	-0.23	0.25	0.12	0.09	0.9294
	Intervention delivery	Existing classroom teacher	3	0.01	-0.23	0.25	0.12	0.09	0.9294
		Recruited personnel	0	-	-	-	-	-	-

Lesson-time physical activity

Data from 16 studies assessing lesson-time physical activity were included (N_{total} = 4660). A random-effects model was applied to the data, as supported by the Q-test of heterogeneity (Q (15) = 626.79, p < .0001). The meta-analysis showed a significant, large, positive effect of physically active lessons on lesson-time physical activity compared to control lessons (SMD = 2.33, 95%CI [1.42, 3.25], p < .0001; Figure 4). The trim-and-fill method used to investigate publication bias suggested there was no publication bias, meaning the estimated number of missing studies is zero. The leave-one-out method used to test the robustness of the findings showed no material change in significance levels or in overall effect size. All moderator tests all showed non-significant results (all *p's* > .18; see Table 1 for subgroup effects).

Figure 4. Forest plot of the effect of physically active lessons on lesson-time physical activity.

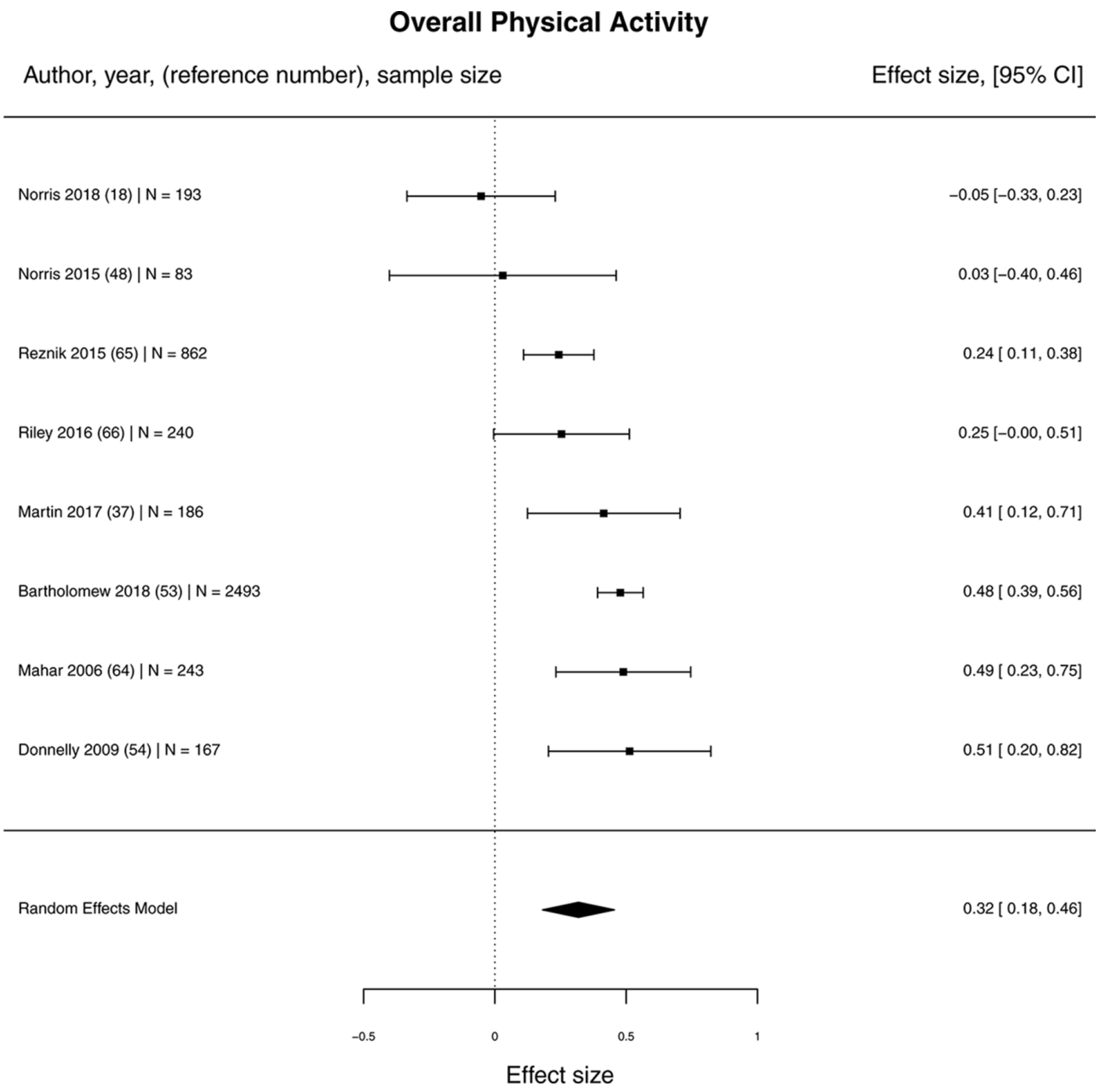


Overall physical activity

Data from 10 studies assessing overall physical activity were included (N_{total} = 4679). A random-effects model was applied to the data, a decision that was supported by the Q-test of heterogeneity (*Q* (9) = 98.67, *p* < .0001). There was a non-significant, medium effect of physical active lessons on overall physical activity (SMD = 0.49, 95%CI [-0.11, 1.10], *p* = .11). No publication bias was detected.

However, the iterative process of the leave-one-out method revealed that this non-significant effect was driven by two influential studies [59] [47]. First, the Trost paper has a very large effect size (SMD=3.71, 95%CI [2.72, 4.71] which, in addition to inflating the overall effect size, substantially widened the 95% confidence interval of the overall effect. Second, the Gammon paper reported less vigorous physical activity in the follow-up of the intervention group compared to control groups (3.0 minutes vs 4.7 minutes), which was extracted following the pre-planned strategy. However, mean difference scores from baseline to post-intervention offered crucial insightful, as the control group decreased vigorous activity by 0.8 minutes compared to 0.1 minutes in the intervention group[47]. The results of our leave-one-out method analyses suggested the possibility for misleading results: for this reason we decided to remove the Gammon paper from the subsequent overall physical activity meta-analysis. When both Trost and Gammon papers were excluded from the sample (leaving N_{total} = 4467), the overall effect size changed from a medium, non-significant effect to a small, yet significant effect (SMD = 0.32, 95%CI [0.18, 0.46], *p* < .0001; Figure 5). All moderator tests showed non-significant results (all *p's* > .25; see Table 1 for subgroup effects).

Figure 5. Forest plot of the effect of physically active lessons on overall physical activity.



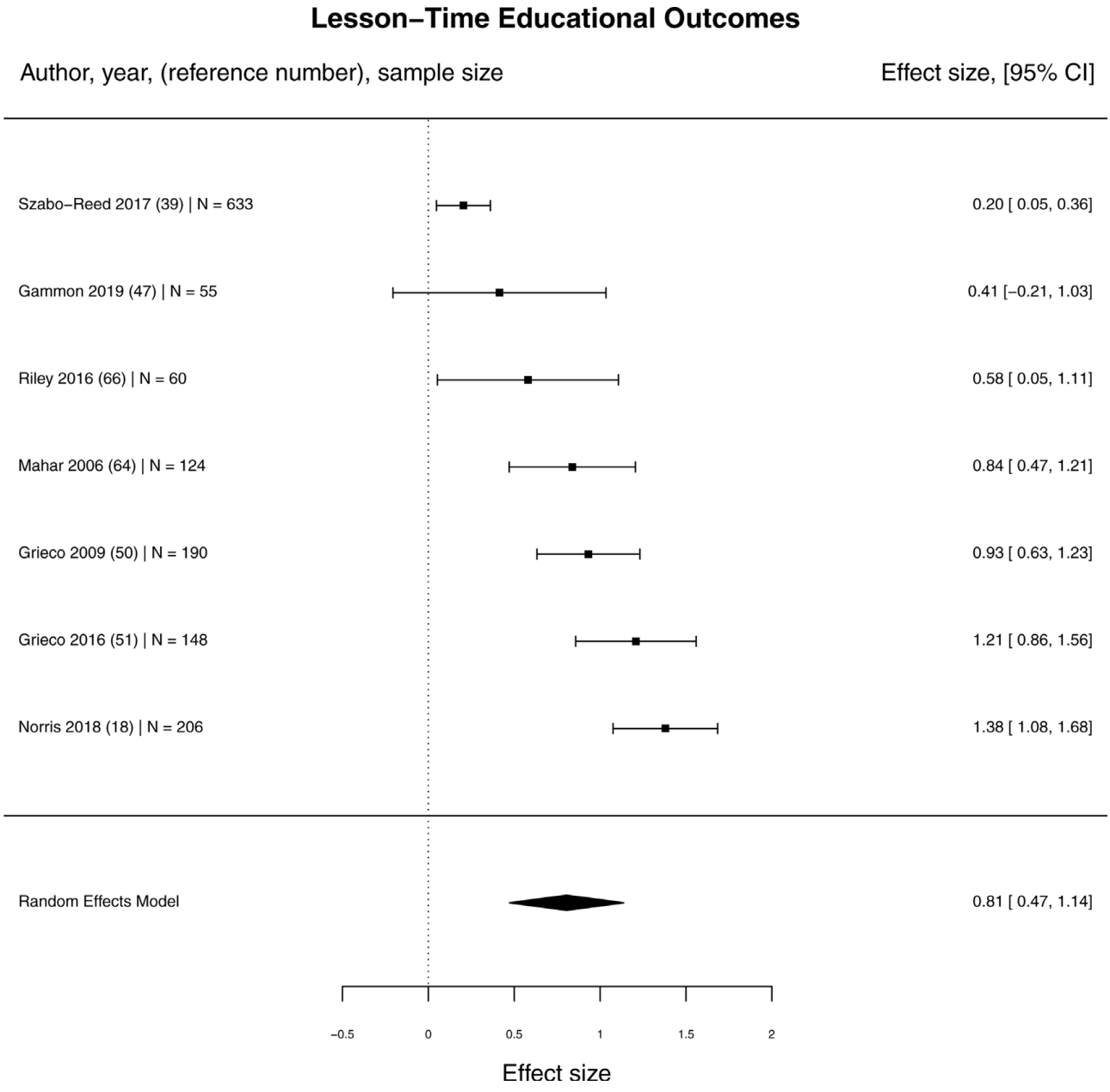
Trost 2008 and Gammon 2019 were removed from final meta-analysis using the leave-one-out method.

Lesson-time educational outcomes

Data from seven studies assessing lesson-time educational outcomes of time-on-task were included (N_{total} = 1416). A random-effects model was fitted to the data, with this decision supported by a Q-test (Q (5) = 67.74, p < .0001). There was a large, significant effect of physically active lessons on lesson-time educational outcomes (SMD = 0.81, 95%CI [0.47, 1.14], p < .0001; Figure 6). There was no sign of publication bias and the leave-one-out sensitivity analysis did not reveal any studies to influence effects.

Intervention length was a significant moderator (Q(1) = 5.71, p = .017), with interventions shorter than 8 weeks showing larger effects (SMD = 0.95, 95%CI [0.68, 1.21]) than interventions longer than 8 weeks (SMD = 0.20, 95%CI [-0.35, 0.75]). This difference needs to be interpreted with caution as the subgroup of interventions longer than 8 weeks consists only of a single study. All other moderators were not significant (all *p's* > .31; see Table 1 for subgroup effects).

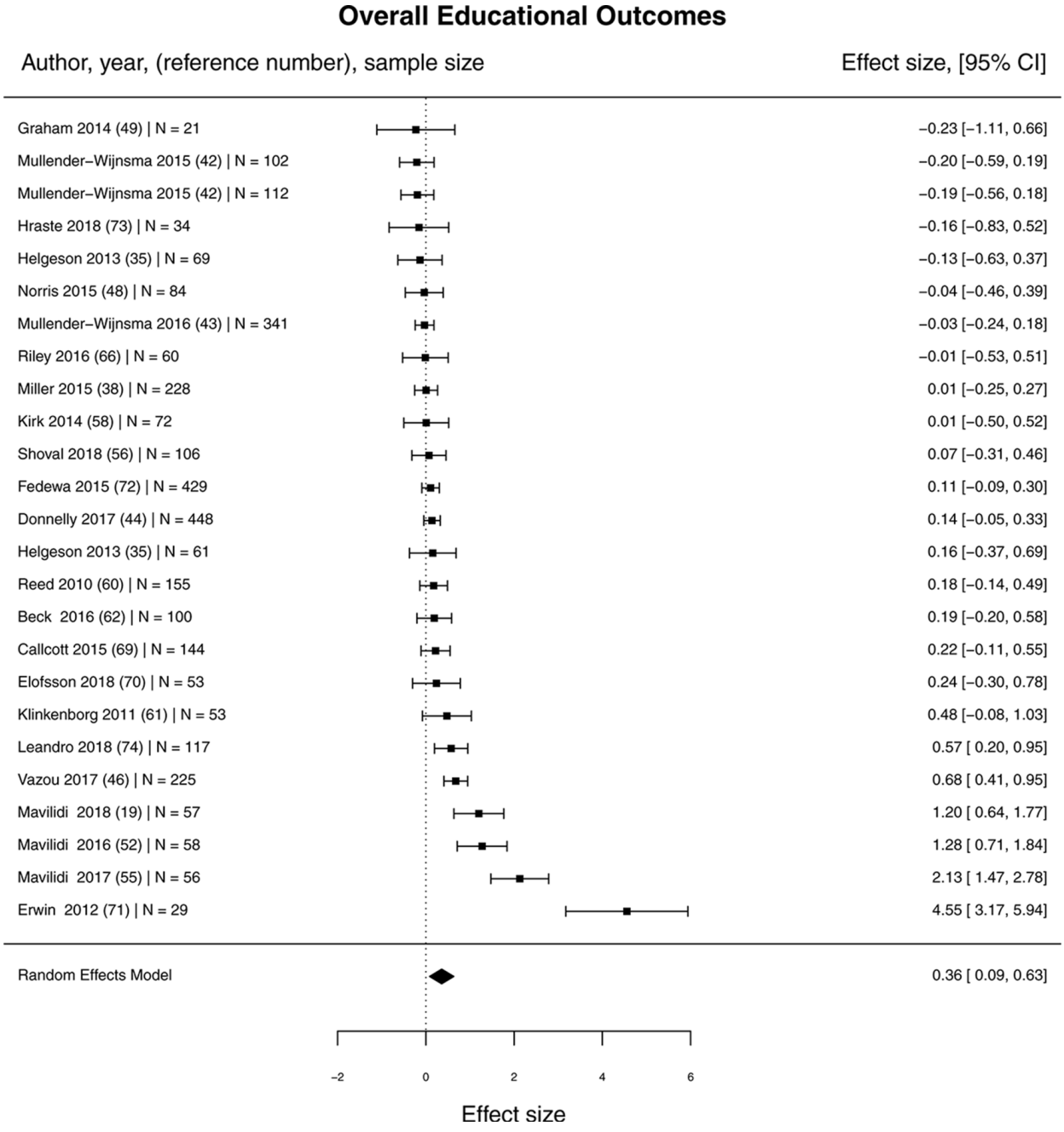
Figure 6. Forest plot of the effect of physically active lessons on lesson-time educational outcomes.



Overall educational outcomes

25 studies assessed educational outcomes (N_{total} = 3214). A random-effects model was applied to the data, again supported by a significant Q-test of heterogeneity (Q (24) = 136.95, p < .0001). There was a small, significant effect of physically active lessons on overall educational outcomes (SMD = 0.36, 95%CI [0.09, 0.63], p < .01; Figure 7). There was no sign of publication bias and the leave-one-out sensitivity analysis did not reveal any studies to influence effects. All moderator tests showed non-significant results (all p's > .09; See Table 1 for subgroup effects).

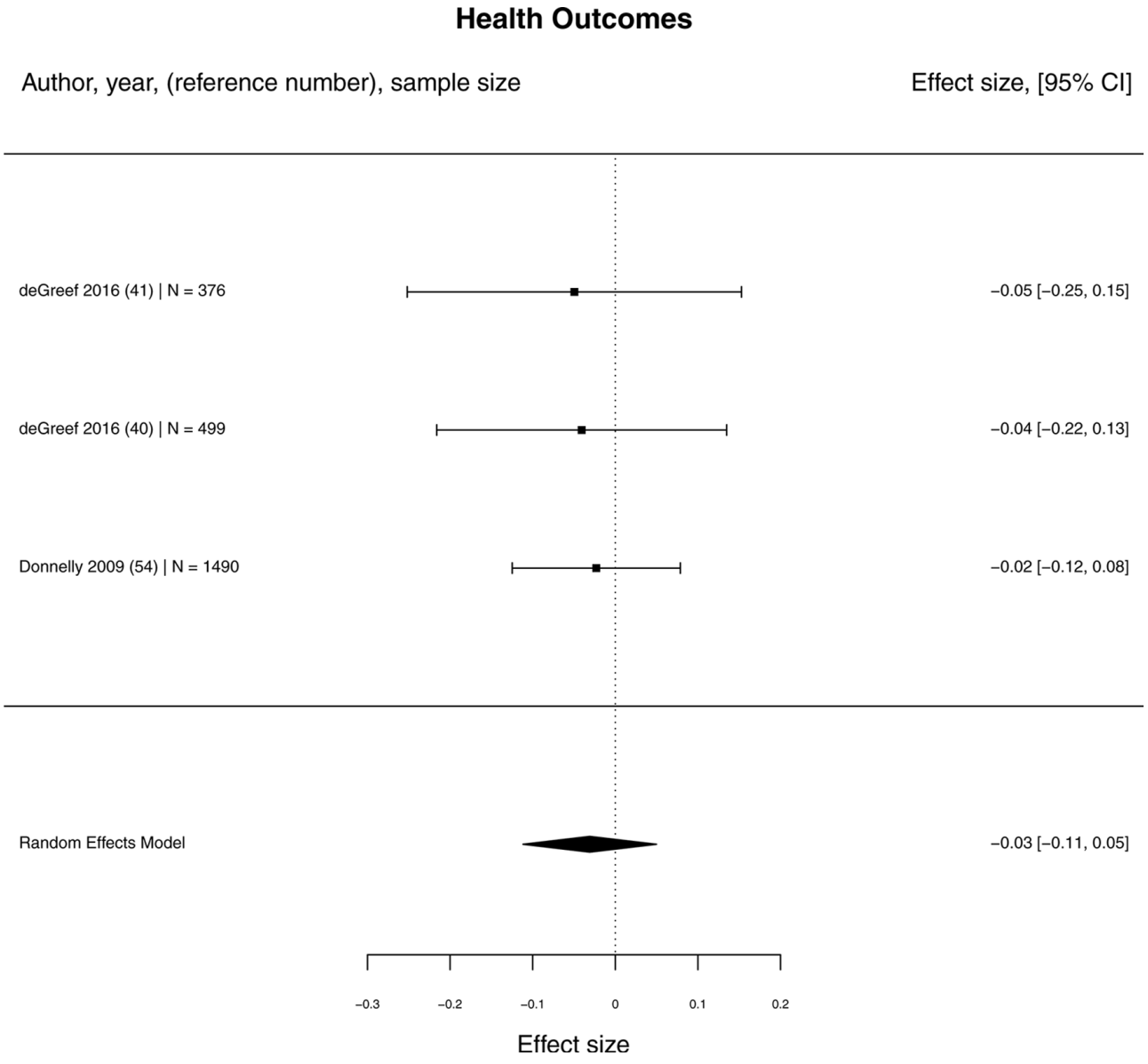
Figure 7. Forest plot of the effect of physically active lessons on overall educational outcomes.



Health outcomes

Data from three studies assessing health outcomes were included (N_{total} =2365), with data from two studies assessing BMI[41 54] and one assessing fitness [40]. While the Q-test of heterogeneity was not significant (Q (2) = 0.07, p = .97), a random-effects models was applied to the data based on the differences in outcome measures across the three studies. There was no effect of physically active lessons on health outcomes (SMD = -0.03, 95%CI [-0.11, 0.05], p=0.45; Figure 8). There was no sign of publication bias and the leave-one-out sensitivity analysis did not reveal any studies to influence effects. All moderator tests showed non-significant results (all *p's* > .84; See Table 1 for subgroup effects).

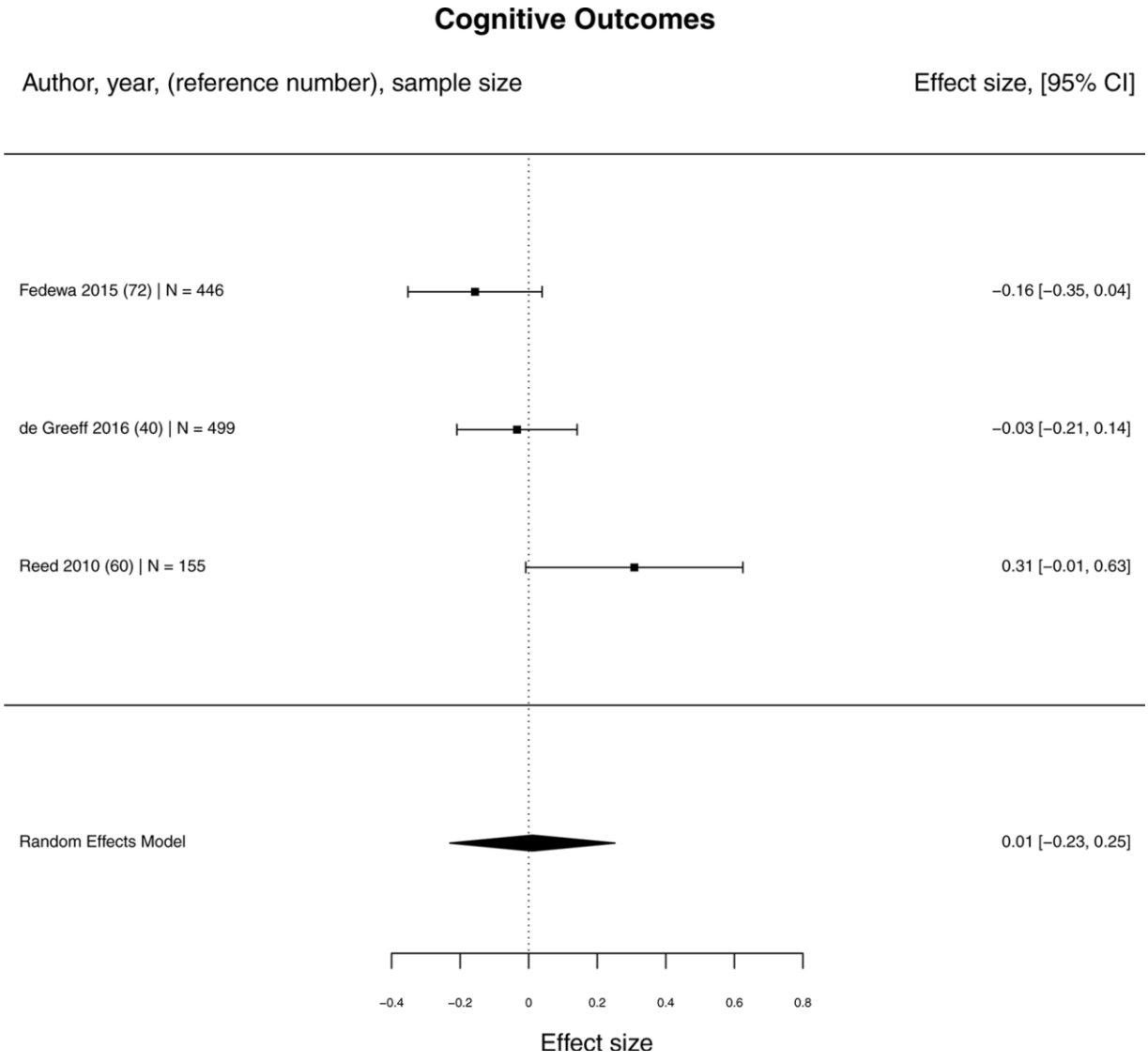
Figure 8. Forest plot of the effect of physically active lessons on health outcomes.



Cognitive outcomes

Data from three studies assessing cognitive outcomes were included (N_{total} =1100), with data from two studies assessing fluid intelligence [60 72] and one assessing executive functions[40] . While the Q-test of heterogeneity (*Q* (2) = 5.98, *p*=0.05) was marginally significant, a random-effects model was applied to the data due to the differences in outcome variables in individual studies. There was no effect of physically active lessons on cognitive outcomes (SMD = 0.01, 95%CI [-0.23, 0.25], *p* =.93; Figure 9). There was no sign of publication bias and the leave-one-out sensitivity analysis did not reveal any studies to influence effects. All moderator tests showed non-significant results (all *p's* =.34; See Table 1 for subgroup effects).

Figure 9. Forest plot of the effect of physically active lessons on cognitive outcomes.



Discussion

This systematic review and meta-analysis identified 42 studies comparing physically active lessons to typical teaching control groups. Physically active lessons produced statistically significant increases in lesson-time and overall physical activity and in lesson-time and overall educational outcomes. No effect was seen on cognitive or health outcomes.

Physically active lessons were found to produce large, significant increases in lesson-time physical activity, accompanied by small, significant effects on overall activity. The smaller observed effect of overall compared to lesson-time activity may indicate a potential compensation effect, whereby children exert lower levels of activity after active lessons to compensate for their earlier increased exertion[77]. An alternative explanation may be that physically active lessons as an 'expansion' of new physical activity opportunities may be insufficient alone to lead to larger increases in overall activity.[78] The combination of expansion activity opportunities with the 'extension' of new activity opportunities and 'enhancement' of wider activity strategies may be needed in schools for larger activity benefits.[78] Overall, these physical activity findings are consistent with previous systematic reviews that qualitatively synthesised results of physically active lessons[15 20 21]. However, this review's findings contrast with a meta-analysis of 11 classroom-based activity interventions of varying content such as active breaks and physically active lessons, which found no effect on observed activity levels[22]. Conducting meta-analyses with strict inclusion criteria to specific intervention characteristics may decrease heterogeneity of interventions and reveal a more accurate estimate of effects.

In contrast to the findings of the first systematic review of physically active lessons in 2015[20], physical activity measurement here was predominantly via objective accelerometers and pedometers, rather than questionnaires or observations. However, the duration of assessment varied greatly, with some studies assessing school-time activity only and others assessing full weekday and weekend day activity [18 54] Between three to seven full days of objective assessment may be necessary to assess change in children's

habitual activity levels[79], however the majority of included studies fell short of this. There was also a consistent lack of physical activity reporting by key demographics, preventing assessment of whether active lessons could improve activity in certain groups at risk of lower activity levels, such as girls and ethnic minorities[1].

Increases in physical activity were not shown to be accompanied by improved health outcomes, as assessed by a small meta-analysis of three studies assessing BMI and cardiovascular fitness[40 41 54]. This lack of effect was seen despite the included studies featuring long intervention periods of between 22 weeks to 3 years, relatively large active lesson doses compared to other studies of around 90 minutes a week and large sample sizes. As such, the lack of effect in this small number of relatively robust studies may suggest that physically active lessons are not sufficient to improve children's BMI and fitness. BMI is arguably not a sufficient measure of health risk in children, as opposed to skinfold thickness and waist circumference assessment[80], suggesting there is a need for more testing of physically active lessons for other valid health outcomes in robust studies.

Significant effects of physically active lessons on education were seen for lesson-time and overall outcomes. This concurs with the meta-analysis of classroom-based physical activity interventions, which found significant increases to both time-on-task and academic achievement[22]. Increased time-on task as a lesson educational outcome may have prompted pupils to pay greater attention to the educational content delivered, translating to knock-on benefits to overall education in the forms of academic achievement[51]. The meta-analysis of available data from three studies in this review found no evidence of benefits to cognitive outcomes of fluid intelligence and executive functions: important pre-cursors to academic outcomes[81]. There was a lack of theoretical basis evident in included studies as to why active learning may facilitate educational improvements. Studies commonly cited previous experimental research indicating learning capacity to increase following acute, intense aerobic exercise as rationale for their interventions [82]

but typically did not extend their rationale to less intense school-based activity nor addressing why knock-on effects may be seen in educational settings.

Strengths & Limitations of identified studies

More robust study designs are evident in the field of physically active lessons since the first review of physically active lessons in 2015[20], as shown by the 42 controlled studies identified here. Longer intervention periods are also apparent, with half of all identified studies having a duration of over 12 weeks, recommended for school-based health interventions[12]. However, few studies had a follow-up period beyond the intervention period. This led to our meta-analyses being restricted to the earliest follow-up only, meaning we could not test whether physically active interventions have a lasting effect beyond their initial implementation period. Although sample sizes have evidently increased [44 53] since the first review of physically active lessons in 2015[20], these samples remain relatively white[83], with a limited number of studies targeting ethnic minority or deprived populations[57 58 61].

High risk of bias was observed in the majority of identified studies. A lack of teachers and pupil blinding in all studies, and a lack of blinding for outcome assessors in one third of studies show that key methodological issues still persist in the area [20]. Such notable bias concurs with other reviews, such as Watson's review of classroom-based activity interventions which identified 36/39 studies to have moderate or weak quality[22] using the Effective Public Health Practice Project (EPHPP) tool[84]. Findings of this review should hence be interpreted with caution, as most studies had methodological weaknesses.

Instances of authors reporting study outcomes from one physically active lesson intervention across multiple papers were apparent. Arguably this restricts teachers', researchers' and policy-makers' access to the full range of available findings for a given intervention, with these papers also often hidden behind multiple pay-walled journals. Readers of one study will hence not receive full details on the methods and

results of a given intervention, limiting the ability to build on the research and limiting the likelihood of full, real-world implementation[85].

The majority of studies did not integrate teachers and schools into the development of physically active lessons, instead providing fairly rigid, pre-developed programmes. Lack of teacher involvement in intervention development can lead to teachers' concerns not been addressed, lower motivation for them to deliver content and lower levels of delivery and fidelity as a consequence[86-89]. This may be evidenced in this review by moderator analyses identifying lower effects on overall educational outcomes for interventions delivered by existing classroom teachers compared to recruited personnel. More inclusive practice is seen in the study of Gammon[47] which focused on the provision of in-depth skills training for physically active teaching, designed to empower teachers to deliver active teaching to high school pupils across subjects. Effective teacher-led approaches are required to allow more sustainable interventions in terms of cost and practicality, compared to recruiting external personnel. More in-depth approaches to physically active lessons such as the provision of in-depth teacher training or co-creation techniques are arguably required to facilitate longer-lasting provision of active lessons[86 90].

A lack of theory behind the development of physically active lesson interventions also remains, with only two studies evidencing a clear theoretical basis[18 37]. Studies also generally did not specify hypothesised pathways of how active lessons may benefit activity, health or educational outcomes. Similar to a related logic model charting the relationship between children's physical activity, cognitive and mental health outcomes[9]; one identified study in our review provided a logic model outlining the relationship between physically active lessons and educational outcomes.[47] This logic model firstly posits the provision of teacher training in active learning principles to increase teacher's confidence and motivation to deliver. Subsequent teacher implementation of active lessons is posited to reduce pupil sedentary behaviour and increase their time-on-task during active lessons, with consequent improvements to pupils lesson enjoyment,

engagement and academic performance[47]. This lack of theory and pathway hypotheses inhibits our ability to assess the mechanisms[90] of why identified positive effects exist for physically active lessons.

Strengths & limitations of this review

This review is the first to meta-analyse the effects of physically active lesson interventions. Strengths of this review include its use of double-coding for all extracted data and its inclusion of controlled studies from single-component interventions to isolate the effects of physically active lessons compared to typical teaching. Limitations of this review include its lack of process evaluation reports of physically active lesson interventions[86] and its exclusive inclusion of English language studies. Studies assessing active breaks were excluded from this review, although it may be that breaks embedded educational content but were not explicitly described to do so. Additionally, this review focused on general school populations only, meaning that effects on children with Special Educational Needs or obesity were not assessed.

Areas for future research

Gaps in the evidence identified in this review suggest a need for research in high schools, longer intervention periods with larger doses of physically active lessons and more comprehensive reporting of health outcomes. A theoretical basis to physically active lesson intervention is also required, to allow assessment of the mechanisms facilitating behaviour change[90]. Facilitation of physically active lessons in the real-world would also be aided by complete reporting of interventions and outcomes in singular studies and co-creation of interventions with schools[89].

Conclusions

This first meta-analysis of physically active lessons found them to significantly increase pupils' physical activity and educational outcomes. No effects were found on cognition or BMI and fitness outcomes. This review shows that physically active lessons can be a useful addition into current curriculum with plausible positive effects on physical activity levels and academic outcomes. Future studies should include longer

follow-up periods, greater doses of physically active lessons, secondary school pupils and assessment of a more diverse range of health outcomes.

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Contributorship statement

All authors approved the review protocol. EN performed searches. EN, AD and TvS performed screening. EN, AD & TvS performed data extraction and risk of bias assessment. EN & TvS wrote the first draft, with all authors contributing to drafts and approving the final version of the manuscript.

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Data sharing statement

Data are available upon reasonable request.

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Supplementary File 1. Summary of included studies.

Study ID	Setting	Study design	Sample	Intervention groups (vs typical teaching)	Duration	Physical activity outcomes assessed	Health outcomes assessed	Cognitive outcomes assessed	Educational outcomes assessed
Bartholomew et al., 2018*[53]	USA Elementary	RCT	n=2493 9-10 years 45.9% male 54.2% ethnic minorities 21.7% free or reduced school meals	1) Active Maths group 2) Active Language Arts group 1x 10-15 min/day	3 years	Accelerometers: Actigraph GT3X+ 5 days During lesson / During school week	N/A	N/A	N/A
Beck et al., 2016*[62]	Denmark Elementary	RCT	n=165 7-8 years 53.3% male	1) Gross Motor Math 2) Fine Motor Math 3x 60min/week	6 weeks	Accelerometers: MinimaxX S4 During lesson	N/A	Visuo-spatial short term memory	Math achievement
Callcott et al., 2015*[69]	Australia Pre-school	Quasi-Experimental	n=297 4-5 years N/A gender	1) Active literacy teaching 2) Phonological teaching 1x 15min/day	1 year	N/A	N/A	N/A	Math performance Spelling achievement Phonological awareness
de Greef et al., 2016a*[41]	Netherlands Elementary	RCT	n=376 7-9 years 43% male	1) Active Maths and Language 3x 20-30 min/week	22 weeks	N/A	BMI; Cardiovascular fitness - Eurofit test battery	N/A	N/A
de Greef et al., 2016b*[40]	Netherlands Elementary	RCT	n=499 7-9 years 45.3% male	1) Active Maths and Language 3x 20-30 min/week	2 school years	N/A	Cardiovascular fitness - Eurofit test battery	Stroop task, Digital span backward, Visual span backward, Modified Wisconsin card sorting	N/A
Donnelly et al., 2009*[54]	USA Elementary	RCT	n=454 7-9 years 42.9% boys 15.3% ethnic minorities 43% free school meals	1) Active lessons across curriculum 10 min, 90min/week	3 years	Accelerometers: Actigraph 7163 4 days During lesson/ During school day During weekend Observations: System for Observing Fitness Instruction Time	BMI	N/A	Academic achievement: Wechsler Individual Achievement Test-2nd Edition (WIAT-II)[65]

						(SOFIT)[64] During lesson			
Donnelly et al., 2017*[44]	USA Elementary	RCT	n=584 7-9 years 48.4% boys 10.5% ethnic minorities 30.6% free or reduced school meals	1) Active lessons across curriculum 2 x 10 min/day	3 years	Observations: SOFIT[64] During lesson	BMI; Fitness: Progressive Aerobic Cardiovascular Endurance Run (PACER)	N/A	Academic achievement: Wechsler Individual Achievement Test-2nd Edition (WIAT-II)[65]
Duncan et al., 2017[45]	UK Pre-school into elementary	RCT	n=74 3-4 years 52.7% boys	1) Storytelling and movement lessons 2x 20-30 min/week	6 weeks	N/A	N/A	N/A	Language ability: British Ability Scales – 3 (BAS3)[66]
Elofsson et al., 2018*[70]	Sweden Pre-school	Quasi-Experimental	n=53 5-6 years 52.8% boys	1) Active Maths 2x 30min/week	3 weeks	N/A	N/A	N/A	Maths ability: Rote counting, number line estimation, verbal arithmetic
Erwin et al, 2012*[71]	USA Elementary	Quasi-Experimental	n=29 8-9 years	1) Active Maths and reading 20min/day	20 weeks	N/A	N/A	N/A	Maths achievement & Reading fluency: Curriculum Based Measurements (CBM)[69]
Fedewa et al., 2015*[72]	USA Elementary	RCT	n=460 8-11 years	1) Active lessons across curriculum 20min/day	8 months	N/A	N/A	Fluid intelligence: Standard Progressive Matrices (SPM)[71]	Maths and Reading achievement: Measures of Academic Progress [MAP];
Gammon et al, 2019*[47]	UK High school	RCT	n=205 11-14 years	1) Active lessons across curriculum No set dose	3 weeks	Accelerometers: AX3 During lesson During school day	N/A	N/A	Time-on-task: Momentary time sampling observation
Graham et al., 2014*[49]	USA Elementary	Non-randomised controlled trial	n=21 7-8 years 52% boys	1) Active Maths with 'Jump-In' mat One-off session, unspecified length	1 day	N/A	N/A	N/A	Content quiz: Researcher developed

Grieco et al., 2009*[50]	USA Elementary	Quasi-Experimental	n=97 8-9 years 45.3% boys 30.7% ethnic minorities	1) Active lesson in unspecified subject One, 10-15min session	1 day	N/A	N/A	N/A	Time-on-task: Momentary time sampling observation
Grieco et al., 2016*[51]	USA Elementary	RCT	n=320 7-12 years 48.8% boys	1) Low to Moderate-intensity Spelling lesson 2) Moderate to vigorous intensity Spelling lesson One, 15min session	1 day	Accelerometers: Actigraph GT1M During lesson During school day	N/A	N/A	Time-on-task: Momentary time sampling observation
Have et al., 2018[63]	Denmark Elementary	RCT	n=505 7-8 years 48% boys	1) Active Maths lessons 6x 45 min/week (including at least 15 mins PA)	1 school year	Accelerometers: Actigraph GT3X During lesson During school day	BMI; Fitness: Shuttle run	N/A	Maths achievement: Standardised test from developer of Danish national tests
Helgeson, 2013*[35]	USA Junior High School	Quasi-Experimental	n=130 12-14 years 50.7% boys 32.6% ethnic minorities 21.3% free or reduced school meals	1) Active English lessons 10-15min/day	4 weeks	N/A	N/A	N/A	Reading comprehension: EasyCBM®
Hraste et al., 2018*[73]	Croatia Elementary	Non-randomised controlled trial	n=36 10-11 years	1) Active Maths lessons 4x 45 min/week	3 weeks	N/A	N/A	N/A	Maths & geometry tests: Researcher developed
Kirk et al., 2014*[58]	USA Pre-school	Quasi-Experimental	n=72 3-4 years 58.3% boys 100% African American	1) Active literacy lessons 2x 15min/day	6 months	Observations: SOFIT[64] During lesson	N/A	N/A	Alliteration, Picture Naming & Rhyming
Kirk et al., 2016*[57]	USA Pre-school	Quasi-Experimental	n=54 3-4 years 31.5% boys 100% African American	1) Active literacy lessons 2x 15min/day	8 months	Observations: SOFIT[64] During lesson	N/A	N/A	Alliteration, Picture Naming & Rhyming
Klinkenborg,	USA	Quasi-	n=54	1) Active Physical	4 weeks	Observations:	N/A	N/A	Physical Science

2011*[61]	Elementary	Experimental	8-9 years 93% ethnic minorities 94% free or reduced school meals	Science lessons 12x 30min sessions over intervention period		SOFIT[64] During lesson			competence: Modified unit assessment
Leandro et al., 2018*[74]	Portugal Elementary	Quasi-Experimental	n=117 7-8 years 56.5% boys	1) Active Maths lessons 1x 60min/week	4 weeks	N/A	N/A	N/A	Content quiz: Researcher developed
Liu et al., 2008[36]	China Elementary	Non-randomised controlled trial	n=753 6-12 years 47.4% boys	1) Active lessons across curriculum 10min/day	9 months	Un-validated questionnaire During lesson	BMI	N/A	N/A
Mahar et al., 2006*[75]	USA Elementary	RCT	n=243 9-10 years	1) Active lessons across curriculum 10min/day	12 weeks	Pedometers: Yamax SW-200 5 school days During school day	N/A	N/A	Time-on-task: Momentary time sampling observation
Martin et al, 2017*[37]	Ireland Elementary	RCT	n=248 8-9 years 51.2% boys	1) Active Maths and English lessons 2x 10min/day	8 weeks	Accelerometers: Actigraph GT3X+ 5 days During lesson During school day	N/A	N/A	N/A
Mavilidi et al., 2016*[52]	Australia Pre-school	RCT	n=87 4-5 years 50% boys	1) Active Geography lesson 3x 10min sessions	1 day	Accelerometers: Actigraph GT3X+/BT During lesson	N/A	N/A	Content quiz: Researcher developed
Mavilidi et al., 2017*[55]	Australia Pre-school	RCT	n=82 4-5 years 49.4% boys	1) Active Science lesson 1x 10min/week	4 weeks	Accelerometers: Actigraph GT1M During lesson	N/A	N/A	Content quiz: Researcher developed
Mavilidi et al., 2018*[19]	Australia Pre-school	RCT	n=115 4-5 years 52.5% boys	1) Active Maths lessons 2) Observing Active Maths lessons 3) Non-integrated activity lessons 1x 15 min/week	4 weeks	Accelerometers: Actigraph GT1M During lesson	N/A	N/A	Maths test: Counting, Number line estimation, Block Counting, Numerical magnitude comparison, Numerical identification

Miller et al., 2015[38]	UK Elementary	RCT	n=372 8-10 years 53% boys	1) Active Maths and English lessons 2x 10-15min/day	6 months	N/A	N/A	N/A	Progress in Maths and English: Pen and pencil administration: Progress in English (PiE) and Progress in Maths (PiM) Computer administration: InCAS Maths and English
Mullender-Wijnsma et al., 2015[42]	Netherlands Elementary	Non-randomised controlled trial	n=228 7-9 years 53.5% boys	1) Active Maths and English lessons 3x 10-15min Maths & 10-15min language/week	21 weeks	N/A	N/A	N/A	Reading ability: E´en-Minuut-Test (1-Minute Test) Maths speed: Tempo-Test-Rekenen (Speed Test Arithmetic)
Mullender-Wijnsma et al., 2016*[43]	Netherlands Elementary	RCT	n=499 7-9 years 45.3% boys	1) Active Maths and English lessons 3x 10-15min Maths & 10-15min language/week	2 years	N/A	N/A	N/A	Reading ability: E´en-Minuut-Test (1-Minute Test) Maths speed: Tempo-Test-Rekenen (Speed Test Arithmetic)
Norris et al., 2015*[48]	UK Elementary	RCT	n=85 9-10 years 58.5% boys 43.5% ethnic minorities	1) Active Virtual Field Trip One, 30min session	1 day	Accelerometers: Actigraph GT1M During lesson/ During school day	N/A	N/A	Content quiz: Researcher developed
Norris et al., 2018*[18]	UK Elementary	RCT	n=264 8-9 years 50.7% boys 52.1% ethnic minorities 22.8% free or reduced school meals	1) Active Maths and English Virtual Field Trip 3x 10min/week	6 weeks	Accelerometers: Actigraph GT1M 4 days During lesson/ During school day/ During weekend Observation: Child's Activity	N/A	N/A	Time-on-task: Observing Teachers and Pupils in Classrooms (OPTIC) tool[78]

						Rating Scale (CARS)[77] observations During lesson			
Reed et al., 2010*[60]	USA Elementary	RCT	n=155 9-10 years 56.7% boys 7.1% ethnic minorities	1) Active Maths, Language & Social Science lessons 3x 30min/week	3 months	Questionnaire: Previous Day Physical Activity Recall (PDPAR)	N/A	Fluid intelligence: Standard Progressive Matrices (SPM)[71]	Academic achievement: Palmetto Achievement Challenge Tests (PACT)
Reznik et al., 2015*[65]	USA Elementary	RCT	n=988 5-7 years 53% boys	1) CHAM-JAM CD with content across curriculum in English & Spanish 3x 10min/day	8 weeks	Pedometers: Yamaz SW-200 5 days During school day	N/A	N/A	N/A
Riley et al., 2015[17]	Australia Elementary	RCT	n=54 10-12 years 51.9% boys	1) Active Maths lessons 3x 60min/week	6 weeks	Accelerometers: Actigraph GT3X 4 days During lesson/ During school day	N/A	N/A	Time-on-task: Momentary time sampling observation
Riley et al., 2016*[66]	Australia Elementary	RCT	n=240 10-12 years 59.1% boys	1) Active Maths lessons 3x 60min/week	6 weeks	Accelerometers: Actigraph GT3X 4 days During lesson/ During school day	N/A	N/A	Maths performance: Progressive Achievement Tests in Mathematics Time-on-task: Momentary time sampling observation
Shoval et al. 2018*[56]	Israel Pre-school	RCT	n=160 4-6 years 59.4% boys	1) Active lessons across curriculum 2) Movement without academic instruction 90 mins indoor and 90 mins outdoor/day	145 days	N/A	N/A	N/A	Maths performance: Maths Achievement Test
Szabo-Reed et al., 2017*[39]	USA Elementary	RCT	n=584 7-10 years 49.5% boys	1) Active lessons across curriculum 2x 10min/day	3 years	Observations: SOFIT [64] During lesson	N/A	N/A	Time-on-task: Momentary time sampling

			18.6% ethnic minorities 28.4% free or reduced school meals						observation
Trost et al., 2008[59]	USA Pre-school	RCT	n=42 3-4 years 54.8% boys	1) Active lessons across curriculum 2x 10min/day	8 weeks	Accelerometers: Actigraph 7164 During school day; Observation: Observational System for Recording Activity in Preschoolers (OSRAP)[81] During lesson	N/A	N/A	N/A
Vazou et al., 2017*[46]	USA Elementary into middle school	Quasi-Experimental	n=284 9-11 years 53.5% boys	1) Active lessons across curriculum 1x 10-12min/day	8 weeks	N/A	N/A	N/A	Maths performance: EasyCBM® Math competence: Shortened perceived competence subscale of the Intrinsic Motivation Inventory (IMI)[82]
Vetter et al., 2018 [75]	Australia Elementary	Quasi-Experimental	n=85 9-10 years 55% boys	1) Active Maths lessons 3x 20min/week	6 weeks	N/A	BMI; Fitness: Shuttle run	N/A	Times tables: Researcher developed

** = studies included in one or more meta-analysis*

Supplementary File 2. Behaviour Change Techniques identified in included physically active lesson interventions.

	Studies (n=42)																					
Behaviour Change Techniques (BCTs) identified	Bartholomew et al., 2018	Beck et al., 2016	Callcott et al., 2015	de Greef et al., 2016a	de Greef et al., 2016b	Donnelly et al., 2009	Donnelly et al., 2017	Duncan et al., 2017	Elofsson et al., 2018	Erwin et al., 2012	Fedewa et al., 2015	Gammon et al., 2019	Graham et al., 2014	Grieco et al., 2009	Grieco et al., 2016	Have et al., 2018	Helgeson et al., 2013	Hraste et al. 2018	Kirk et al., 2014	Kirk et al., 2016	Klinkenborg et al., 2011
Goal setting (behaviour) (1.1)														■					■	■	
Problem solving (1.2)												■									
Action planning (1.4)																					
Monitoring of behaviour by others without feedback (2.1)	■																■				
Feedback on behaviour (2.2)			■	■	■					■									■	■	
Self-monitoring of behaviour (2.3)				■	■		■							■		■	■		■	■	
Social support (unspecified) (3.1)																■				■	
Social support (practical) (3.2)																				■	
Instruction on how to perform the behaviour (4.1)	■	■	■	■	■	■	■			■	■	■	■	■		■	■	■	■	■	
Information about health consequences (5.1)				■	■																
Information about social and environmental consequences (5.3)																■					
Demonstration of the behaviour (6.1)			■									■						■			
Instruction on others' approval (6.3)																					
Prompts / cues (7.1)																■				■	
Behavioural practice/rehearsal (8.1)																					
Behavioural substitution (8.2)																					
Habit reversal (8.4)																					
Generalisation of target behaviour (8.6)																					
Credible source (9.1)																					
Material reward (behaviour) (10.2)																					
Non-specific reward (10.3)																					
Restructuring the physical environment (12.1)		■																			■
Restructuring the social environment (12.2)				■	■	■									■				■	■	
Adding objects to the environment (12.5)	■	■	■	■	■		■			■	■		■	■			■				■
Identification of self as role model (13.1)							■														
Framing/reframing (13.2)																					

Behaviour Change Techniques (BCTs) identified	Leandro et al., 2018	Liu et al., 2008	Mahar et al., 2006	Martin et al., 2017	Mavilidi et al., 2016	Mavilidi et al., 2017	Mavilidi et al., 2018	Miller et al., 2015	Mullender-Wijnsma et al., 2015	Mullender-Wijnsma et al., 2016	Norris et al., 2015	Norris et al., 2018	Reed et al., 2010	Reznik et al., 2015	Riley et al., 2015	Riley et al., 2016	Shoval et al., 2018	Szabo-Reed et al., 2017	Trost et al., 2008	Vazou et al. 2017	Vetter et al., 2018
Goal setting (behaviour) (1.1)			■	■								■		■					■	■	
Problem solving (1.2)				■				■													■
Action planning (1.4)				■								■									
Monitoring of behaviour by others without feedback (2.1)								■	■					■							
Feedback on behaviour (2.2)									■	■						■			■		
Self-monitoring of behaviour (2.3)				■						■		■		■		■		■	■	■	
Social support (unspecified) (3.1)								■													■
Social support (practical) (3.2)																■					
Instruction on how to perform the behaviour (4.1)	■	■	■	■				■	■	■	■	■	■			■	■	■	■		■
Information about health consequences (5.1)			■						■			■				■					
Information about social and environmental consequences (5.3)																					
Demonstration of the behaviour (6.1)														■					■		
Instruction on others' approval (6.3)				■								■									
Prompts / cues (7.1)				■								■				■					
Behavioural practice/rehearsal (8.1)			■																■		
Behavioural substitution (8.2)				■							■	■									
Habit reversal (8.4)				■																	
Generalisation of target behaviour (8.6)				■																	
Credible source (9.1)				■				■				■				■					
Material reward (behaviour) (10.2)					■	■	■														
Non-specific reward (10.3)																		■			
Restructuring the physical environment (12.1)																	■				
Restructuring the social environment (12.2)	■					■	■		■	■					■						■
Adding objects to the environment (12.5)		■	■		■	■	■		■	■	■	■		■		■		■	■	■	■
Identification of self as role model (13.1)																					
Framing/reframing (13.2)																					■

Supplementary File 3. Overview of included studies, which meta-analyses they appeared in and their moderator codings.

Study	Meta-analysis						Moderators						
	Lesson-time physical activity	Overall physical activity	Health outcomes	Cognitive outcomes	Lesson-time educational outcomes	Overall educational outcomes	Risk of Bias	Study design	Intervention length	Number of sessions	School type	Physical activity measurement	Intervention delivery
Bartholomew et al., 2018	Yes	Yes	No	No	No	No	High	RCT	< 8 weeks	>1 session	>Pre-school	Objective	Existing classroom teacher
Beck et al., 2016	Yes	No	No	No	No	Yes	Low	RCT	< 8 weeks	>1 session	>Pre-school	Objective	Existing classroom teacher
Callcott et al., 2015	No	No	No	No	No	Yes	High	Not RCT	> 8 weeks	>1 session	Pre-school	N/A	Existing classroom teacher
de Greef et al., 2016a	No	No	Yes	No	No	No	Low	RCT	> 8 weeks	>1 session	>Pre-school	N/A	Recruited Personnel
de Greef et al., 2016b	No	No	Yes	Yes	No	No	High	RCT	> 8 weeks	>1 session	>Pre-school	N/A	Existing classroom teacher
Donnelly et al., 2009	Yes	Yes	Yes	No	No	No	Low	RCT	> 8 weeks	>1 session	>Pre-school	Objective	Existing classroom teacher
Donnelly et al., 2017	Yes	No	No	No	No	Yes	High	RCT	> 8 weeks	>1 session	>Pre-school	Objective	Existing classroom teacher
Duncan et al., 2017	No	No	No	No	No	No	High	RCT	< 8 weeks	>1 session	Pre-school	N/A	Recruited Personnel
Elofsson et al., 2018	No	No	No	No	No	Yes	High	Not RCT	< 8 weeks	>1 session	Pre-school	N/A	Existing classroom teacher
Erwin et al, 2012	No	No	No	No	No	Yes	High	Not RCT	> 8 weeks	>1 session	>Pre-school	N/A	Existing classroom teacher
Fedewa et al., 2015	No	No	No	Yes	No	Yes	Low	RCT	> 8 weeks	>1 session	>Pre-school	N/A	Existing classroom teacher

Gammon et al., 2019	No	Yes	No	No	Yes	No	High	RCT	< 8 weeks	>1 session	>Pre-school	Objective	Existing classroom teacher
Graham et al., 2014	No	No	No	No	No	Yes	High	Not RCT	< 8 weeks	1 session	> Pre-school	N/A	Existing classroom teacher
Grieco et al., 2009	No	No	No	No	Yes	No	High	Not RCT	< 8 weeks	1 session	> Pre-school	N/A	Existing classroom teacher
Grieco et al., 2016	Yes	No	No	No	Yes	No	Low	RCT	< 8 weeks	1 session	> Pre-school	Objective	Recruited Personnel
Have et al., 2018	No	No	No	No	No	No	Low	RCT	> 8 weeks	>1 session	> Pre-school	Objective	Existing classroom teacher
Helgeson, 2013	No	No	No	No	No	Yes	High	RCT	< 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Hraste et al., 2018	No	No	No	No	No	Yes	Low	Not RCT	< 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Kirk et al., 2014	No	No	No	No	No	Yes	Low	Not RCT	> 8 weeks	>1 session	Pre-school	N/A	Existing classroom teacher
Kirk et al., 2016	Yes	No	No	No	No	No	Low	Not RCT	> 8 weeks	>1 session	Pre-school	Subjective	Existing classroom teacher
Klinkenborg, 2011	Yes	No	No	No	No	Yes	High	Not RCT	< 8 weeks	>1 session	> Pre-school	Subjective	Recruited Personnel
Leandro et al., 2018	No	No	No	No	No	Yes	High	Not RCT	< 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Liu et al., 2008	No	No	No	No	No	No	High	Not RCT	> 8 weeks	>1 session	> Pre-school	Subjective	Existing classroom teacher
Mahar et al., 2006	No	Yes	No	No	Yes	No	High	Not RCT	< 8 weeks	>1 session	> Pre-school	Objective	Existing classroom teacher
Martin et al,	Yes	Yes	No	No	No	No	Low	RCT	< 8 weeks	>1 session	> Pre-	Objective	Existing

2017											school		classroom teacher
Mavilidi et al., 2016	Yes	No	No	No	No	Yes	Low	RCT	< 8 weeks	1 session	Pre-school	Objective	Recruited Personnel
Mavilidi et al., 2017	Yes	No	No	No	No	Yes	Low	RCT	< 8 weeks	>1 session	Pre-school	Objective	Recruited Personnel
Mavilidi et al., 2018	Yes	No	No	No	No	Yes	Low	RCT	< 8 weeks	>1 session	Pre-school	Objective	Recruited Personnel
Miller et al., 2015	No	No	No	No	No	Yes	High	RCT	>8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Mullender-Wijnsma et al., 2015	No	No	No	No	No	Yes	Low	Not RCT	> 8 weeks	>1 session	> Pre-school	N/A	Recruited Personnel
Mullender-Wijnsma et al., 2016	No	No	No	No	No	Yes	Low	RCT	> 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Norris et al., 2015	Yes	Yes	No	No	No	Yes	High	RCT	< 8 weeks	1 session	> Pre-school	Objective	Existing classroom teacher
Norris et al., 2018	Yes	Yes	No	No	Yes	No	High	RCT	< 8 weeks	>1 session	> Pre-school	Objective	Existing classroom teacher
Reed et al., 2010	No	No	No	Yes	No	Yes	High	RCT	> 8 weeks	>1 session	> Pre-school	Subjective	Existing classroom teacher
Reznik et al., 2015	No	Yes	No	No	No	No	High	RCT	< 8 weeks	>1 session	> Pre-school	Objective	Existing classroom teacher
Riley et al., 2015	No	No	No	No	No	No	High	RCT	< 8 weeks	>1 session	> Pre-school	Objective	Recruited Personnel
Riley et al., 2016	Yes	Yes	No	No	Yes	Yes	High	RCT	< 8 weeks	>1 session	> Pre-school	Objective	Existing classroom teacher
Shoval et al., 2018	No	No	No	No	No	Yes	High	RCT	> 8 weeks	>1 session	Pre-school	N/A	Existing classroom teacher
Szabo-Reed et	Yes	No	No	No	Yes	No	High	RCT	> 8 weeks	>1 session	> Pre-	Objective	Existing

al., 2017											school		classroom teacher
Trost et al., 2008	Yes	Yes	No	No	No	No	Low	RCT	< 8 weeks	>1 session	Pre-school	Objective	Existing classroom teacher
Vazou et al., 2017	No	No	No	No	No	Yes	High	Not RCT	< 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher
Vetter et al., 2018	No	No	No	No	No	No	High	Not RCT	< 8 weeks	>1 session	> Pre-school	N/A	Existing classroom teacher