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Methodological considerations and impact of school-based interventions on objectively measured physical activity in adolescents: A systematic review and meta-analysis

Ron Borde[1], Jordan J. Smith[2], Rachel Sutherland[3,4,5], Nicole Nathan[3,4,5] & David R. Lubans[2]§

[1] Division of Training and Movement Sciences, Research Focus Cognition Sciences, University of Potsdam, Potsdam, Germany

[2] Priority Research Centre in Physical Activity and Nutrition, University of Newcastle, Callaghan, NSW, Australia

[3] Hunter New England Population Health, Wallsend, NSW, Australia

[4] School of Medicine and Public Health, University of Newcastle, Callaghan, NSW, Australia

[5] Hunter Medical Research Institute, Lambton, NSW, Australia

§ **Corresponding author**

Professor David R. Lubans

School of Education

Faculty of Education and Arts

University of Newcastle

Callaghan NSW Australia 2308

+ 61 2 4921 2049 (Phone)

+ 61 2 4921 7407 (Fax)

David.Lubans@newcastle.edu.au

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ABSTRACT

Objective: The aims of this systematic review and meta-analysis are: (i) to determine the impact of school-based interventions on objectively measured physical activity among adolescents; and (ii) to examine accelerometer methods and decision rule reporting in previous interventions.

Methods: A systematic search was performed to identify randomized controlled trails targeting adolescents (age: ≥ 10 years), conducted in the school setting, and reporting objectively measured physical activity. Random effects meta-analyses were conducted to determine the pooled effects of previous interventions on total and moderate-to-vigorous physical activity (MVPA). Potential moderators of intervention effects were also explored.

Results: Thirteen articles met the inclusion criteria and twelve were included in the meta-analysis. The pooled effects were small and non-significant for both total physical activity (SMD=0.02 [95%CI = -0.13 to 0.18]) and MVPA (SMD=0.24 [95%CI = -0.08 to 0.56]). Sample age and accelerometer compliance were significant moderators for total physical activity, with a younger sample and higher compliance associated with larger effects.

Conclusion: Previous school-based physical activity interventions targeting adolescents have been largely unsuccessful, particularly for older adolescents. There is a need for more high quality research using objective monitoring in this population. Future interventions should comply with best-practice recommendations regarding physical activity monitoring protocols.

INTRODUCTION

Physical inactivity is linked to a number of non-communicable diseases [17], and is the fourth leading risk factor for mortality globally [59]. As such, there is an urgent need to support physical activity participation across the life course. The period of adolescence appears to be a critical stage for the establishment of behavioral habits that can either support or undermine future health status [47], and evidence suggests physical activity during youth tracks into adulthood [52]. Of concern, moderate-to-vigorous physical activity (MVPA) declines by approximately 7% per year between the ages of 12 and 18 [10, 18, 44], and 80% of adolescents globally fail to satisfy current physical activity recommendations (i.e., at least 60 minutes of MVPA each day) [7, 17, 36]. Although many inactivity-related chronic diseases take years to manifest, mental health problems emerge during adolescence [13] and physical activity is an important protective behavior for this class of health problems [30]. Taken together, these findings suggest adolescents are a priority population for interventions aimed at promoting physical activity.

Schools are considered important settings for physical activity promotion, as no other institution has more contact with youth during the first two decades of life [21, 50]. Previous reviews suggest school-based interventions have been successful in increasing physical activity and improving cardiorespiratory fitness [5, 9, 25, 26, 29, 34, 46, 57]. However, prior studies have utilized a range of outcome measures, which may vary considerably in terms of their validity. Correlations between self-reported and objectively measured physical activity are typically poor (i.e., coefficients ranging from .19 to .50) [1, 3, 22, 24, 48], and self-report measures have been shown to overestimate MVPA by between 57 and 88 min/week [1, 3, 22, 24, 48]. Although self-report and accelerometry are essentially evaluating different things (i.e., physical activity behavior versus raw movement), these findings suggest that self-report measures may overestimate the effect of interventions. Objective assessment is therefore a more appropriate method for evaluating the impact of physical activity programs in schools. In 2012, Metcalf and colleagues [34] published a meta-analysis which aggregated the findings of intervention trials using high quality study designs and objective measures of physical activity (i.e., accelerometers). In contrast to the more positive message of prior reviews, the study authors reported only small pooled effects for total physical activity and MVPA, and concluded the impact of prior interventions has been trivial [34]. It is important to note, however, that only six of the 30 included studies in this review targeted adolescents in a school-based intervention [34]. Consequently, the impact of interventions targeting this population remains unclear.

Since 2012, the number of published physical activity intervention studies that have targeted adolescents, and used objective measures has increased [35]. In addition, prior reviews have failed to adequately detail the possible impact of different monitoring protocols on physical activity outcomes. Indeed, previous studies have utilized different devices, different criteria to determine valid wear-time, and have assessed physical activity over varying periods [35]. Moreover, compliance with physical activity monitoring protocols varies considerably between studies [35], which could have a meaningful influence on both individual study conclusions and the comparability of findings between studies. Given the increasing popularity of objective physical activity assessment, it is important to gain a better understanding of the range of methodologies used in past youth intervention research, and to test for the potential influence of these factors on study findings. Consistent with previous research [34], the examination of traditional moderators of intervention effects (e.g., sample age and intervention characteristics) is also warranted. Therefore, the aims of this systematic review and meta-analysis are to: (i) determine the impact of school-based interventions on objectively measured physical activity among adolescents, and (ii) examine the potential impact of accelerometer methods and decision rule reporting in adolescent physical activity interventions.

METHODS

The present meta-analysis follows the recommendations of the 'Preferred Reporting Items for Systematic Reviews and Meta-Analyses' (PRISMA) [28].

Search Strategy

A systematic literature search was conducted without date constraints in seven online databases CINAHL® Plus with Full Text, The Cochrane Library, EMBASE®, Ovid MEDLINE®, PsychINFO®, Scopus, SPORTDiscus^{TM}. The following search terms were included in our Boolean search syntax: (adolescen* OR youth OR teen) AND (“school based” OR “physical education” OR “physical break” OR exercise OR training) AND (“physical activity” OR sedentary OR obesity OR BMI) AND (objective* OR acceleromet* OR "activity monitor" OR actigraph OR MTI OR CSA tactical OR actiheart OR tritrac OR unidimensional OR triaxial OR MVPA) AND (randomized OR controlled OR trial OR RCT OR intervention). The following additional filters were used in the different databases if available: English language, human species, age (school child [7 to 12 years] and adolescent [13 to 17 years]), and randomized controlled trial. In addition, the reference lists of included full-text articles and other convenient systematic reviews and meta-analyses, as well as authors’ own libraries were checked for relevant studies.

Eligibility Criteria

Two independent reviewers (RB, RS) assessed the eligibility of the studies using the following inclusion criteria, which was in accordance with the PICOS approach [(28)]: (a) population: studies that included adolescents with a study mean age of 10 years or older; (b) intervention: school-based interventions aimed at increasing physical activity; (c) comparator: controls who did not receive an intervention aimed to increase physical activity (participation in regular physical education or sports participation was allowed); (d) outcome: total physical activity level [counts per time] and/or MVPA [min per day] measured using accelerometry; and (e) study design: randomized controlled trails [(28)]. Studies were excluded if: (a) the intervention targeted a clinical population (e.g., youth with Cerebral Palsy or Down’s Syndrome); (b) the intervention duration was shorter than four weeks; or (c) not published in a peer-reviewed journal.

Data Extraction and Coding of Studies

The main study characteristics were extracted using an Excel template/spreadsheet. Studies were coded for the following variables: (a) sample size; (b) age; (c) duration of intervention; (d) intervention components (i.e., single- or multi-component intervention); (e) measures of physical activity (i.e., total physical activity, MVPA); (f) accelerometer type and number of axes (i.e., uni-, bi-, tri-axial); (g) compliance with wear-time criteria at baseline and post-test; (h) systematic differences between wear-time compliers and non-compliers; and (i) intervention participants (i.e., targeted sample, whole-of-school). If data were missing, the authors of the respective studies were contacted via email. Five out of 13 authors responded to requests and sent missing data.

Criteria for Risk of Bias Assessment

Risk of bias was assessed independently by two authors (RB, NN). All included studies were examined using a methodological checklist (Table 1.). The checklist was developed with reference to PRISMA guidelines. Each item was coded as 'clearly described and present' (✓), 'absent' (×) or 'inadequately described' (?). Using a dichotomous scale (✓= 1; × or ? = 0), the inter-rater reliability was calculated using percentage agreement and Kappa analysis. Disagreements between authors were resolved by discussion. The individual items were not numerically summarized to give a final score, rather each criterion was considered in isolation [28]. Criteria A, B, C, and G were regarded as the most significant items in which bias could have an impact on results [20, 28].

Statistical Analyses

To determine the overall effects of school-based interventions on objectively measured physical activity, the standardized mean differences (SMD) were calculated according to the following formula: $SMD_i = \frac{m_{1i}-m_{2i}}{s_i}$ [8], where SMD_i is the standardized mean difference of one reported parameter (e.g., total PA or MVPA), m_{1i}/m_{2i} corresponds to the mean of the intervention and the control group, and s_i is the pooled standard deviation. In accordance with Hedges and Olkin, this formula was adjusted for sample size: $g = \left(1 - \frac{3}{4N_i-9}\right)$ [19], where N_i is the total sample size of intervention group and control group. SMD is defined as the difference between the post-test means of the intervention and control groups divided by the pooled standard deviation with 95% confidence intervals (CIs). The meta-analysis was conducted using Review Manager Version 5.3.4 (Copenhagen: The Nordic Cochrane Centre, The Cochrane Collaboration, 2008). Included studies were weighted by the standard error: $SE\ \{SMD_i\} = \sqrt{\frac{N_i}{n_{1i}n_{2i}} + \frac{SMD_i^2}{2(N_{i-3.94})}}$ [8], where n_{1i} is the sample size of the intervention group and n_{2i} is the sample size of the control group. Given the variability between studies for a number of contextual factors (e.g., sample age, intervention type, accelerometer protocols etc), it was decided that a random-effects model was the most appropriate for estimating the effects of interventions [27, 28]. To consider possible baseline differences between the intervention and control groups, a baseline adjusted SMD was calculated by subtracting the SMD of the baseline values from the SMD of the post intervention [11]. According to Cohen, effect size values of 0.00 to ≤ 0.49 indicate small, values of 0.50 to ≤ 0.79 indicate medium, and values ≥ 0.80 indicate large effects [6]. Heterogeneity was assessed using I^2 and χ^2 statistics. Furthermore, a random-effects moderator analysis was calculated to examine whether the effects of school-based interventions on total physical activity and MVPA differed according to key moderating variables. The software Comprehensive Meta-analysis version 3.3.070 (Biostat Inc., NJ, USA) was used [4, 12, 53]. Subcategories were created to determine the most important variables for the effects of interventions on total physical activity and MVPA. The moderators were based on sample demographics (i.e., age and study sample), characteristics of the intervention (i.e., duration, intervention components, sample size) and accelerometer methods (i.e., compliance with monitoring protocols). The following variables were calculated as categorical: study sample (i.e., targeted sample or whole-of-school), intervention type (single- or multi-component), and compliance (<50% or ≥50% of sample compliant with accelerometer protocols). For total physical activity, the number of studies within each of the moderator categories were as follows: Study sample (targeted = 3 studies, whole of school = 4 studies); intervention components (single = 1 study, multiple = 6 studies); compliance at baseline (<50% = 1 study, ≥50% = 5 studies); compliance at post-test (<50% = 2 studies, ≥50% = 4 studies). For MVPA, the number of studies within each of the moderator sub-categories was as follows: Study sample (targeted = 5 studies, whole of school = 6 studies); intervention components (single = 4 studies, multiple = 7 studies); compliance at baseline (<50% = 3 studies, ≥50% = 8 studies); compliance at post-test (<50% = 3 studies, ≥50% = 8 studies). For the different subcategories, random-effects moderator analysis was performed to identify the variables that most predicted differences in the effect sizes for total physical activity and MVPA.

RESULTS

The systematic search from databases and other sources identified 2,535 potential articles (Figure 1). After removing duplicates, 1712 articles were screened by title and abstract. Of these, 135 articles underwent full text assessment, and a total of 13 articles with 11,515 subjects (median sample size = 1083 subjects) and a mean age of 12.4 years (age range: 11-16 years) were included in the analyses (Table 2). Two studies (31, 42) were conducted with girls only, two (39, 49) with boys only, and one study (38) specifically targeted overweight and obese adolescents. With regards to the physical activity outcome, seven out of 13 studies reported total physical activity, 12 studies reported MVPA, and six studies reported both.

Risk of Bias assessment

The risk of bias assessments for the included studies are summarized in Table 3. The inter-rater reliability showed a percentage agreement of 84% across the 104 items (k = 0.75). Most studies reported adequate results for each group (2, 14, 16, 32, 38, 39, 42, 45, 49, 51, 54, 60) and presented baseline characteristics separately for treatment groups for at least one outcome measure (2, 14-16, 32, 38, 42, 45, 49, 51, 60). Assessor blinding was reported in three studies (39, 49, 51), and in seven studies, all allocated subjects were analysed and not excluded because of missing data or non-compliance (2, 32, 39, 42, 49, 51, 54). Seven studies adjusted for covariates in their statistical analyses (2, 14, 16, 39, 42, 51, 60), and eight studies included an *a priori* power calculation to determine the required sample size (2, 14, 32, 42, 45, 49, 51, 54). Acceptable participant retention (i.e., no more than 30% drop-out) was reported in nine studies (2, 15, 32, 38, 39, 42, 45, 49, 60).

Overview of Intervention components

The intervention duration ranged from four weeks (15) to 28 months (2) with a median duration of nine months. Four studies utilised single component interventions to promote physical activity (15, 38, 39, 42) while nine studies employed multiple intervention components (2, 14, 16, 32, 45, 49, 51, 54, 60). Physical activity promotion strategies within the studies included active breaks (14, 16, 32, 45, 49, 51), health education (14, 16, 32, 45, 49, 54, 60), healthy food information (14, 16, 32, 60), extra physical activity lessons (32, 49, 51, 54, 60), pedometers [14, 32, 45, 49], parental engagement [14, 32, 49, 51], newsletters [14, 32, 49], and sports equipment [14, 16, 49, 54].

Overview of accelerometer usage

All but one of the studies [60] used Actigraph brand accelerometers, and the number of axes differed between one [14, 16, 32, 39, 45, 60], two [2, 14, 32, 38, 42] and three [15, 32, 49, 51, 54]. The accelerometer monitoring period ranged from five weekdays [2] to eight consecutive days [45]. There was considerable variability across studies with regards to the criteria for valid accelerometer wear time. Studies included participants' physical activity data in the final analysis if accelerometers were worn: at least two school days [15], at least 10 hours on at least two days [14], at least 10 hours on at least three days [38, 42, 45, 49, 51, 54], and at least 10 hours on four days [32, 39]. Three studies used no fixed threshold regarding wearing hours and days. Specifically, two studies accepted any days with at least 540 min and 960 min [2, 16], and one study [60] did not report any wear-time inclusion criteria. Participant compliance with minimum required wear-time ranged from 44% to 99% (mean = 72% ± 16%) at baseline and from 25% to 96% (mean = 61% ± 20%) at post-test. Only one study reported a systematic difference between compliers and non-compliers. Grydeland and colleagues [14] reported that girls were more likely to provide valid data than boys.

Overall Findings

Meta-analyses of seven studies reporting total physical activity (Figure 2) showed a clear lack of intervention effects. The pooled effect was trivial and non-significant (pooled SMD = 0.02 [95% CI = -0.13 to 0.18]), and the significant I^2 value of 64% (χ^2 = 16.74; *df* = 7; p = 0.01) suggests the presence of moderate to substantial heterogeneity. Twelve studies examined the effects of school-based interventions on MVPA (Figure 3). The pooled effect for MVPA was larger than that for total physical activity. However, the effect was also small and not statistically significant (pooled SMD = 0.24 [95% CI = -0.08 to 0.56]). As demonstrated by the I^2 value of 96%, there was substantial heterogeneity for studies evaluating MVPA (χ^2 = 278.06; *df* = 11; $p < 0.01$).

Moderator Analyses

Moderator analyses were conducted separately for total physical activity and MVPA. Possible moderators were analysed across the three key subcategories: population, intervention and accelerometer (Table 4). For total physical activity, the age of the study sample was found to moderate the effects of interventions ($p < 0.05$). Studies conducted with adolescents under 13 years of age resulted in a weighted pooled SMD of 0.08 (95% CI = -0.06 to 0.22), whereas those conducted with adolescents 13 years and older resulted in a weighted pooled SMD of -0.26 (95% CI = -0.50 to 0.02). None of the characteristics of interventions were found to moderate intervention effects for total physical activity or MVPA. However, accelerometer compliance was found to be a significant moderator for total physical activity ($p < 0.05$). Studies with greater than or equal to 50% compliance at post-test resulted in a weighted pooled SMD of 0.45 (95% CI = -0.48 to 1.39), whereas those with a compliance rate lower than 50% resulted in a weighted pooled SMD of -0.18 (95% CI = -0.36 to -0.01). No significant moderating effects were found for MVPA ($p = 0.25$ to 0.93).

DISCUSSION

Previous research suggests school-based interventions aimed at increasing physical activity have been less effective for adolescents compared with younger children [(58)]. However, such conclusions have been limited by the small number of studies conducted with adolescents. The relatively greater number of studies included in the present meta-analysis suggests a renewed research interest in physical activity promotion among adolescent populations. The primary aim of this systematic review and meta-analysis was to examine the effects of school-based interventions on objectively measured physical activity among adolescents. Our findings suggest the effects of prior interventions have been small and non-significant. A secondary aim of this study was to investigate accelerometer methods and decision rule reporting and potential impact in adolescent physical activity interventions. Of note, our analysis demonstrated that compliance with accelerometer protocols moderated the effect of interventions on total physical activity. Specifically, studies with higher compliance at post-test (i.e., at least 50%) tended to report larger intervention effects.

The present study provides a timely update of the effects of interventions targeting adolescents. For example, both the most recent Cochrane review of school-based interventions (2013) [9] and the review by Metcalf and colleagues (2012) [34] included just six studies with adolescents. By contrast, the present review identified more than double this number, with 13 relevant trials included. Our findings suggest the effects of school-based interventions targeting adolescents have been trivial, which is largely consistent with the findings of previous reviews and meta-analyses [5, 9, 25, 26, 29, 34, 46, 57]. Metcalf and colleagues [34] reported small but significant effects (SMD = 0.12 [95% CI = 0.04 to 0.20] for total physical activity; SMD = 0.16 [95% CI = 0.08 to 0.24] for MVPA) for interventions targeting both children and adolescents, equating to approximately four additional minutes of physical activity per day. Small effects for total physical activity (SMD = 0.02 [95% CI = -0.13 to 0.18]) and MVPA (SMD = 0.24 [95% CI = -0.08 to 0.56]) were observed in the present study, equating to approximately 2 additional minutes of MVPA per day for adolescents receiving an intervention. However, the pooled effects were not statistically significant. Although the pooled effect sizes in previous reviews have also been small, they are larger than those observed in the present study. This is likely due to the inclusion of studies with younger children and those using self-report measures. The overestimation of physical activity from self-report [1, 3, 22, 24, 48] as well as the greater number of studies included by collapsing interventions directed at all youth, is likely to have inflated the effect estimates and increased statistical power. One of the few studies to report a significant and meaningful effect on objectively measured was the Physical Activity 4 Everyone trial [51]. This comprehensive intervention included seven physical activity components and six implementation adoption strategies, including the provision of an in-school physical activity consultant. These findings highlight the substantial challenges and extensive support required to increase physical activity in adolescent populations, but also demonstrate an efficacious strategy for improving adolescents' physical activity behaviors within the school setting.

A novel contribution of the current review is the detailed description of accelerometer monitoring protocols within included studies, and moderator analysis examining the effects of such protocols on trial findings. Although considered to be a valid and reliable method for measuring physical activity, accelerometry is not without its own limitations [33]. Key limitations with implications for the comparison or pooling of studies, are the variation in monitoring periods, classification of minimum wearing days, and definitions for determining a 'valid day'. Our findings highlight the considerable heterogeneity between studies with regards to each of these important decision rules. Of the trials included in this meta-analysis, the monitoring periods varied from five weekdays to eight consecutive days, with the most common being seven (i.e., 57% of studies) then five (21% of studies) days. There is some evidence that as few as four days of monitoring can provide a reliable estimate of habitual physical activity [56]. However, it has been suggested that a seven day monitoring period is the most sensible choice when evaluating youth physical activity participation [56].

In addition to the length of the monitoring periods, there was also substantial variability in the selection of wear-time criteria (i.e., minimum days and daily wear-time hours). When reported, minimum wearing days and hours ranged from 'at least two school days' to 'at least 10 hours per day on at least four days', with the most common protocol being 'at least 10 hours per day on at least three days' (i.e., 43% of studies). Decisions regarding wear-time can have a significant impact on the quantity of missing data, as compliance naturally declines with increasingly stringent wear-time requirements. Of concern, a recently published systematic review reported that missing accelerometer data (due to a combination of drop-out and non-compliance) is highest in studies with adolescents (mean = 52.9%) [23], and in school-based interventions (mean = 42.2%). Rich and colleagues [41] have suggested that the minimum required wear-time to maximise the proportion of participants with usable data and achieve a high reliability (i.e., r = .86) is two days with at least 10 valid hours. However, their analysis was conducted with seven year old children and may therefore not be generalizable to older youth.

As more stringent wear-time criteria tended to result in greater numbers of excluded participants (particularly at post-test), the significant moderating effect of wear-time compliance likely reflects the fact that studies with more achievable wear-time thresholds (i.e., fewer days and/or hours required for a valid day) were more likely to have reported positive findings. This is problematic, as these studies are also the least likely to have adequately captured the 'habitual' physical activity of study participants. For example, a liberal wear-time criteria of 'at least eight hours on at least two days', is likely to result in relatively high participant compliance, but may fail to capture much of an adolescent's usual physical activity. Previous evidence suggests adolescents' day-to-day physical activity is more variable than it is for younger children [(55)]. Consequently, it appears particularly important for interventions targeting adolescents to specify conservative wear-time criteria (i.e., in terms of both number of days and hours). Such decisions are challenging for intervention researchers as large quantities of missing data introduce another kind of study bias, and adolescents are typically less compliant with accelerometry than their younger peers [(23)]. Another possible explanation for this moderating effect is that higher quality studies, that more effectively engaged study participants, were more likely to report positive findings. Indeed, compliance with monitoring could be viewed as a proxy for participant satisfaction and engagement, as adolescents that see value in the intervention itself would also be more likely to see value in the assessment of their physical activity behavior. Conversely, interventions with poor fidelity, that failed to engage schools, teachers and students, would be expected to result in relatively fewer adolescents complying with the physical activity assessment. Finally, there may be other demographic factors that explain poor compliance to accelerometer monitoring protocols. For example, a British cohort study (N = 13,681) of young people found that non-compliers were more likely to be: i) male, ii) overweight/obese, iii) inactive, and iv) low socio-economic status [(40)]. Therefore, it is not surprising that poor compliance is found in studies targeting low-active adolescents from low-income communities.

Risk of Bias

Each included study in this meta-analysis demonstrated some bias, as only two of the studies satisfied all methodological items considered to have the greatest influence on study findings: randomization, blinded assessors, application of intention-to-treat analysis, and low dropout rate [(39, 49)]. The overall methodological quality of the studies can be described as moderate, as for seven out of eight items more than half of the studies described and presented those items adequately. The item 'assessor blinding' was satisfied by only three studies [39, 49, 51].

Strengths and limitations

To the authors' knowledge, this is the first systematic review and meta-analysis that examine the effects of school-based interventions on objectively measured physical activity in adolescents. A key strength of the present meta-analysis is the inclusion of studies using accelerometry to measure physical activity. Accelerometers are considered the 'gold standard' field-based measure of physical activity, and studies using subjective measures such as self-report may be overestimating their effectiveness [43]. Studies were typically at moderate risk of bias, and many trials did not adequately report study characteristics (e.g., data of pre- and post-test, compliance etc). Another limitation is the moderate-to-high heterogeneity between included studies, which indicates a large variability in outcomes (i.e., total physical activity and MVPA) and methodologies (e.g., components of interventions, accelerometer protocols). Finally, given the relatively small number of included studies, the findings of the moderator analyses should be interpreted with caution.

CONCLUSION

This systematic review and meta-analysis showed small and non-significant effects of school-based interventions on objectively measured physical activity among adolescents. Secondary analyses revealed significant moderating effects of population age and compliance with monitoring protocols, with younger adolescents and higher compliance associated with larger effects. Although the present study identified a greater number of adolescent trials compared with previous reviews, the overall number of interventions targeting this population remains relatively small. Our review suggests that prior school-based interventions have been unsuccessful, and extensive support is likely required to reduce the decline in physical activity typically observed among adolescents. It should also be noted that the variability in accelerometer protocols between studies makes a definitive conclusion challenging. Interventionists should comply with best-practice principles regarding accelerometer measurement. This will lead to improved confidence in study conclusions, and will enable more valid comparisons of study findings. To promote physical activity among this priority population, there is clearly a need to design interventions that include extensive implementation strategies [(37)]. However, the distinct lack of effects identified by our meta-analyses also suggests that increasing adolescents' physical activity may require a new paradigm and creative ideas. Researchers should therefore continue to explore novel intervention approaches to address physical inactivity in this group.

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Tables

Table 1. Risk of bias assessment check list

A	Randomization (generation of allocation sequence, allocation concealment and implementation) clearly described and adequately completed
B	Blinded outcome assessment (positive when those responsible for assessing PA were blinded to group allocation of individual participants)
C	Participants analyzed in the group they were originally allocated to, and participants not excluded from analyses because of non-compliance to treatment or because of some missing data
D	Covariates accounted for in analyses (e.g., baseline score, group/cluster for cluster RCTs, and other relevant covariates where appropriate, such as age or sex)
E	Power calculation reported for primary outcome (i.e., PA)
F	Presentation of baseline characteristics separately for treatment groups (at least one outcome measure)
G	Dropout for primary outcome described, with 30 % dropout at follow-up
H	Summary results for each group + (estimated effect size (difference between groups)) + its precision (e.g., 95 % confidence interval)

PA = physical activity; RCT = randomized controlled trial

Table 2. Studies examining the effects of school-based intervention on objectively measured physical activity

Study	N[1]	Age (years)	Period	Type of Intervention	Outcome	Accelerometer type	Wearing time of Accelerometer	Compliance with accelerometer wear-time (Pretest – Postest)	Differences in adherence to wear time criteria [a]	Targeted Participants
Andrade et al. [(2)]	1083	12.7	28 mths	Multi-component IG: - Health education - Workshops for parents - Organization of social event - Environmental modifications CG: - usual PE practice	Total PA (CPM/day) MVPA (min/day)	Actigraph GT-256 and GT1M (biaxial) (Subgroup-n: 134)	5 weekdays Inclusion: ≥ 540 min per day	BA: 94% (240-226) PI: 53%	No difference between adolescents who wore or not the accelerometer in terms of BMI, BMI z-score, gender, fitness and screen time (p>0.05)	
Grydeland et al. [(14)]	1528	11.2	20 mths	Multi-component IG: - handbooks of healthy food and PA - Poster sessions - Healthy break meals - PA break - Sports equipment - Active campaigns - Pedometer - Information for parents (food and PA) - Teacher training and information CG: - no intervention	Total PA (CPM) MVPA (min/day)	Actigraph MTI 7164 (uniaxial), Actigraph GT1M (biaxial)	5 consecutive days Inclusion: ≥ 8 h on at least 3 days	BA: 79% (1129/1439) PI: 61% (700/1129)	No differences in age, BMI, weight category or parental education between students who provided valid accelerometer data against the ones who did not provide valid data at both time points Significantly more boys were in the group without valid accelerometer data (p<0.001)	
Ha et al. [(15)]	1386	12.0	1 mth	IG: - Rope skipping workshop for PE teachers - Rope skipping program - Student handbooks - Extra sport	MVPA (min/day)	Actigraph GT3X+ (triaxial) (Subgroup-n: 454)	5 consecutive schooldays (only during school hours) Inclusion: ≥ 2 or more schooldays	BA: 99% PI: 96%	N/R	

[1] Sample size of analyzed subjects

				equipment - Rope skipping corner CG: - no intervention						
Haerens et al. [16]	2287	13.1	24 mths	Multi-component IG1: - healthy food choices - PA breaks - Extra non-competitive activities organized by school - Extra sport equipment - Active transport - Cycling during class - PA and food tailored feedback IG2: - Intervention like IG1 + Parental involvement (health education) CG: - no intervention	MVPA (min/day)	Actigraph MTI 7164 (uniaxial) (Subgroup-n: 183)	6 days 4 weekdays and 2 weekend days Inclusion: days with ≥960 min of registered activity	BA: 89.7% PI: 89.5%	N/R	
Lubans et al. [32]	357	13.2	12 mths	Multi-component IG: - enhanced school sport sessions - interactive seminars - nutrition workshops - lunch time PA - nutrition hand books - parent newsletters - pedometers for self-monitoring - text messaging for social support CG: - no intervention	Total PA (CPM) MVPA (min/day)	Actigraph GT1M (biaxial) and GT3X (triaxial)	7 consecutive days Inclusion: ≥ 10h on at least 4 days	BA: 53.5% PI: 24.9%	N/R	Girls only
Pbert et al. [38]	82	15.8	2 mths	IG: - School nurse	MVPA (min/day)	Actigraph GT1M (biaxial)	7 consecutive days	BA: 85% (71/82) PI: 68% (62/82)	N/R	Overweight and obese

				delivered counseling sessions including discussions and help to be active and eat healthy CG: - School nurse delivered counseling sessions including weigh and information of weight management			Inclusion: ≥ 10h on at least 3days			adolescents
Peralta et al. (39)	23	12.5	6 mths	IG: - Lunch time PA - Information of healthy living - Parent information sessions - newsletters CG: No intervention	Total PA (CPM) MVPA (min/day)	Actigraph MTI 7164 (uniaxial)	7 consecutive days Inclusion: ≥ 10h on at least 4 days	BA: 84% PI: 82% (calculated)	N/R	Boys only
Robbins et al. (42)	69	11.5	6 mths	IG: - Extra PA lessons - School nurse delivered counseling sessions including discussions and help to be active and eat healthy CG: - Workshops with health-promoting topics such as building self-esteem or career exploration	MVPA (min/hour)	Actigraph GT1M (biaxial)	7consecutive days Inclusion: ≥ 8h on at least 4 days At least one weekend day	BA: 44% PI: 44%	N/R	Girls only
Salmon et al. (45)	278	10.7	9 mths	IG1: (behavioural modification [BM]) - Health education to increase PA and reduce screen time - Pedometer - Group games IG2 (fundamental motor	Total PA (CPM) MVPA (min/day)	Actigraph MTI 7164 (uniaxial)	8 consecutive days Inclusion: ≥ 10h on at least 3 days	N/A	N/R	

				skills [FMS]) - Games and activities to improve FMS IG3 - Combination of IG1 and IG2 CG: - no intervention						
Smith et al. [49]	361	12.7	8 mths	Multi-component IG: - Teacher professional development - Provision of fitness equipment - Parent newsletter - Seminars for students - enhanced school sport sessions - Lunch time PA - Smartphone app and Web site - Pedometers CG: - no intervention	Total PA (CPM)	Actigraph GT3X+ (triaxial)	7 consecutive days Inclusion: ≥ 10h on at least 3 weekdays ≥10 h on at least one weekend day	BA: 66.5% (240/361) PI: 41% (120/293)	N/R	Boys only
Sutherland et al. [51]	1150	12.0	12 mths	Multi-component IG: - Provision of teaching strategies - Development of individual student PA plans - enhanced school sport - School PA policies - PA during school breaks - Provision of links to community PA providers - Parental engagement CG:	MVPA (min/day)	Actigraph GT3X+ and GT3X (triaxial)	7 consecutive days Inclusion: ≥ 10h on at least 3 days	BA: 78% (965/1150) PI: 61% (643/1050)	N/R	

				- no intervention					
Toftager et al. [54]	1348	12.5	24 mths	Multi-component IG: - Upgrade of existing school outdoor areas for PA - Development of play spots - Improvements of safety for active transport to and from school - Establishment of an after school fitness program - Formulation and implementation of school PA policy - Education for teachers - Establishment of a school play patrol - Mandatory outdoor recess, free access gym - School traffic patrol - Training of safe cycling for students - School project week CG: - no intervention	Total PA (CPM) MVPA (min/day)	Actigraph GT3X (triaxial)	7 consecutive days Inclusion: ≥ 10h on at least 3 days	BA: 91% (1233/1348) PI: 65% (797/1233)	N/R
Wilson et al. [60]	1563	11.3	17 weeks	Multi-component IG: - heathy food information - PA choices - Motivational strategies - Behavioural skills training CG: - no intervention	MVPA (min/day)	Phillips Actical (uniaxial)	7 consecutive days Inclusion: No criteria	no inclusion criteria	N/R

BA = Baseline; CG = Control group; CPM = counts per minute; IG = Intervention group; mths = months; MVPA = moderate to vigorous physical activity; N/A = not available; N/R = not reported;

PA = physical activity; PI = post intervention; [a] = predictors of compliance of wearing Accelerometer

Table 3. Summary of risk of bias assessment of included studies

Study	A Randomization	B Blind assessor	C Intention-to-treat analysis	D Covariates accounted for in analyses	E Power calculation for primary outcome	F Baseline comparability	G Dropout ≤ 30%	H Summary results
Andrade et al. [2]	✓	×	✓	✓	✓	✓	✓	✓
Grydeland [14]	✓	×	×	✓	✓	✓	×	✓
Haerens et al. [16]	✓	×	×	?	×	✓	✓	✓
Ha et al. [15]	✓	×	×	✓	×	✓	?	×
Lubans et al. [32]	✓	×	✓	×	✓	✓	✓	✓
Pbert et al. [38]	✓	×	×	?	×	✓	✓	✓
Peralta et al. [39]	✓	✓	✓	✓	×	×	✓	✓
Robbins et al. [42]	✓	×	✓	✓	✓	✓	✓	✓
Salmon et al. [45]	✓	×	×	?	✓	✓	✓	✓
Smith et al. [49]	✓	✓	✓	?	✓	✓	✓	✓
Sutherland et al. [51]	✓	✓	✓	✓	✓	✓	×	✓
Toftager et al. [54]	✓	×	✓	?	✓	×	×	✓
Wilson et al. [60]	✓	×	×	✓	×	✓	✓	✓

✓ = explicitly described and present; × = absent; ? = unclear or inadequately described.

Table 4. Moderator analysis for variables of different subcategories to predict school-based intervention effects on total PA

	Coefficient	Standard error	95 % lower CI	95 % upper CI	Z value	P value
Population						
Intercept	-1.9822	0.8501	0.3160	3.6483	2.33	< 0.05
Age	-0.1657	0.0652	-0.2935	-0.0379	-2.54	< 0.05
Target	0.0977	0.1219	-0.1413	0.3367	0.80	
Intervention						
Intercept	0.1551	0.4826	-0.7908	1.1009	0.32	
Duration	0.0081	0.0166	-0.0244	0.0407	0.49	
Intervention components	-0.4298	0.5352	-1.4787	0.6191	-0.80	
Sample size	0.0003	0.0004	-0.0006	0.0011	0.60	
Accelerometer						
Intercept	-0.1441	0.1989	-0.5355	0.2522	-0.71	< 0.05
Compliance pre	-0.0292	0.0123	-0.0499	-0.0098	-2.82	< 0.01
Compliance post	0.0068	0.0032	0.0001	0.0127	1.98	< 0.05

CI = confidence interval; *pre* = baseline; *post* = post-intervention.